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Canada/NB MDA Project on Mine-shaft Rope Testing;
testing of 1" Ø Hoist Rope (our rope #1)

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MRL #90-131 (TR) December, 1990

47 pp

91-02414/

CANADA/NB MDA PROJECT ON MINE-SHAFT ROPE TESTING; TESTING OF 1" Ø HOIST ROPE (OUR ROPE #1)

by

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ABSTRACT

In this report the authors analyse the test-results obtained both non-destructively, and destructively, on a 1.000 in. diameter hoist-rope (H.R.). The rope was examined both in situ and on the shop-floor as part of CANMET's project to comparatively evaluate the performance of a range of EM wire-rope testers. This is the first time that a project of this magnitude and diversity has been undertaken.

The rope, when tested in situ, was reported to contain strength losses (LBS) of up to 11.0%, with moderate to extensive corrosion, in addition to interstrand wear. Both the in situ and shop-floor reports refer to this rope as being of 1.000 in. diameter. However, the field reports refer to it as an 18×7 rope, while the shop-floor reports state that it was of 6×27, F.S., construction. The authors were unable to clarify the origin of this contradiction.

In the field, EM testing was performed with one American (the LMA-250) and two Canadian (the Rotescograph, and Magnograph) instruments. The same instruments, as well as the Canadian Rotesco AC and the prototype version of a West German tester, designed by WBK's rope testing laboratory, were used on the shop-floor.

The results obtained are analysed with special reference to such important parameters as their repeatability, comparability, and levels of accuracy.

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Keywords: New Brunswick; Mineral Development Agreement; Wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Head-ropes

PROJET DE L'EEM CANADA/N.-B SUR L'ESSAI DE CÂBLES DE PUITS DE MINES; ESSAI D'UN CÂBLE D'EXTRACTION DE 1 PO DE DIAMÈTRE (NOTRE CÂBLE N^{O} 1)

par

L.B. Geller*, D. Poffenroth**, J.E. Udd*** et D. Hutchinson****

RÉSUMÉ

Dans le présent rapport, les auteurs analysent les résultats d'essais réalisés par des méthodes non destructives et par des méthodes destructives sur un câble d'extraction de 1,000 po de diamètre. Le câble a été examiné in situ et en atelier dans le cadre d'un projet de CANMET visant à faire une évaluation comparative du rendement d'une gamme d'appareils d'essais électromagnétiques (ÉM) de câbles métalliques. C'est la première fois qu'on réalise un projet d'une telle envergure et d'une telle diversité.

L'essai effectué in situ a montré que le câble présentait des pertes de résistance à la rupture allant jusqu'à 11,0 %, avec une corrosion de moyenne à forte, ainsi qu'une usure entre les torons. Dans le rapport de l'essai in situ et dans celui de l'essai en atelier, on considère que le câble a un diamètre de 1,000 po. Cependant, les rapports de l'essai sur le terrain spécifient un câble 18x7, alors que les rapports de l'essai en atelier spécifient un câble 6x27, F.S. (torons aplatis), construction. Les auteurs ont été incapables d'expliquer l'origine de cette contradiction.

Sur le terrain, des essais EM ont été effectués avec un appareil américain (le LMA-250) et deux appareils canadiens (le Rotescograph et le Magnograph). En atelier, on a utilisé les mêmes appareils ainsi que l'appareil canadien Rotesco AC et la version prototype d'un appareil d'essai ouest-allemand, conçu par le laboratoire d'essais de câbles de WBK.

On analyse les résultats obtenus en accordant une attention particulière à des paramètres importants comme la répétabilité, la comparabilité et les niveaux de précision.

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Mots-clés : Nouveau-Brunswick; entente sur l'exploitation minérale; câbles métalliques; essais non destructifs; appareils électromagnétiques; câbles de tête.

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BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in 1986 in response to requests by both the mining industry and the mine regulatory authorities. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be examined, documented, analysed, and the reasons for these occurrences clarified. This is the first time a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (1, 2, 3, 4). We are now in the process of reporting the results obtained during the contracted project-phase, which included an extensive series of both in situ and shop-floor tests. The first seven reports to describe this project phase were published in the period February through August, 1990 (5, 6, 7, 8, 9, 10, 11). This is the eighth report in the series. More are to follow.

ROPE DETAILS

The rope which is the subject of this report (referred to as "our rope #1") was used as a hoist-rope on a drum-hoist at J.S. Redpath's First Canadian mine-site, Val d'Or, Quebec.

According to the field reports, it was of a 1.000 in. diameter, 18 × 7 construction. When tested on the shop-floor, however, the rope purporting to have been sent by the mine at Val d'Or was seen to be of 1.000 in., 6 × 27, F.S., construction. Unfortunately, it proved impossible to clarify this contradiction, because the mine had recently been sold to Ressources Aur, and all relevant background documentation (relating to rope construction, purchase, installation, maintenance, and the like) seems to have been mislaid. Consequently, we were also unable to obtain copies of any previous destructive and non-destructive test-results. We can, therefore, only state that the average breaking strength of the previously listed 1.000 in., 6 × 30, mine-shaft ropes (1) was 107,698 lb, the weakest of this range breaking at 84,250 lb, and the strongest at 125,000 lb.

IN SITU TEST RESULTS — AS REPORTED AND REVIEWED

General procedure

The in situ tests were undertaken, under standard operating conditions, with two Canadian (the Magnograph, and Rotescograph) and one American (the LMA-250) instruments. All of the tests were performed completely independently of each other by operators known to, and approved by, the instrument makers/designers. None of the operators knew about each other's results before these were submitted to us.

The Magnograph data

As explained previously, we were unable to obtain copies of earlier destructive and non-destructive test results of this rope, or of any of its predecessors and companion-ropes. Our own Magnograph test was performed on 1988 09 09*. The operator submitted the strip-chart reproduced in Fig. 1a. The rope length tested was 439 yards (1,317 ft). The maximum reported LMA (LMA_{max}) was 4.5% (report #88-433) at 380 yards (1,140 ft) from the start of the test at the conveyance rope-end. The 100% reference level was chosen at the conveyance rope-end. No LBS estimates were submitted by the instrument operator. However, he reported six broken wires, possibly three each in two strands, some 6 yards (18 ft) from the start of the test.

On reviewing the operator's chart, we agreed with the reported LMA readings.

The Rotescograph data

Our in situ Rotescograph test was performed on 1988 09 15. A copy of the instrument chart is reproduced in Fig. 2a. The rope length tested was some 2,060 ft, including an approximately 120 ft section between the head-sheave and drum which, apparently, was not tested by either of the other two operators. The operator reported (test #SQR-5) an LBS of some 11.0% at 1,115-1,117 ft, and at 1,122-1,124 ft from the start of the test above the skip-cage. At 38-44 ft the reported LBS estimate was 7.5% to 8.0%. Elsewhere, the estimated LBS did not exceed 7.0% to 7.5%. Moderate to extensive corrosion, as well as interstrand wear, was reported along the first 1,700 ft of tested rope above the conveyance.

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* dates are given in this order: year; month; day.

A major anomaly, associated with a broken wire, was reported at 95 ft from the drum when the rope was fully extended in the shaft. This anomaly is at the drum rope-end, possibly in a section which was not tested by the Magnograph and LMA-250 operators.

Other than questioning the rope-length indication along the strip-chart, we agree with the operator's report.

The LMA-250 data

Our in situ LMA-250 test was performed on 1988 09 09. A copy of the instrument chart, as submitted to us by the operator, is reproduced in Fig. 3a. Tested rope length was some 1,290 ft. The operator reported an LMA_{max} of 4.8% at 465 ft from the test-start at the drum rope-end, and a 3.0% LMA at 1,180 ft.

A broken wire was reported at 135 ft, and a large gap at 1,250 ft from the drum rope-end. The 1,250 ft location translates into a distance of some 40 ft from the rope's drum-end. The Magnograph operator also reported major wire breaks 18 ft from the conveyance rope-end. Interestingly, the Rotescograph operator reported a major wire-break only at the drum rope-end, although an LF trace perturbation, indicative of possible wire-breaks, can be detected some 18 ft from the conveyance rope-end as well.

We agree with the operator's chart readings.

SHOP FLOOR TEST RESULTS — AS REPORTED AND REVIEWED

General procedure

The shop-floor tests were undertaken with three Canadian (the Rotesco AC, Rotescograph, and Magnograph), one American (the LMA-250), and a West German tester (the prototype version of the latest German WBK instrument). None of the operators knew about each other's results before these were submitted to us. All details of the testing process have been described, and illustrated, elsewhere (5).

The Magnograph data

Shop-floor testing with the Magnograph was undertaken on 1989 04 04. The operator reported an LMA_{max} of 5.5% (report #89-286J) at 540 ft from test-start.

The test-chart is reproduced in Fig. 1b. The rope length tested appears to have been 1,449 ft; the accuracy of the operator's chart-splicing at the 426 yard (1,278 ft) mark seems, however, questionable. The operator marked the 5.5% LMA_{max} reading on his chart. The operator did not mark any other LMA readings.

Comparing the in situ (Fig. 1a) and shop-floor (Fig. 1b) strip-charts it would appear that: (1) they probably are of the same rope, (2) testing started at the conveyance rope-end in each case, (3) in both cases the 0.0% LMA is at the conveyance rope-end, and (4) that the LMA difference between the conveyance- and drum rope-ends is about 2.0% in the field vs 0.0% on the shop-floor. The latter actually appears to be in error. In any case, however, according to these test-results the %LMA data read off the in situ strip-chart need not be adjusted, because both in situ and shop-floor results were obtained relative to the same 'best' rope section.

The question often arises as to how useful, and instructive, are the LBS test results that are routinely obtained — on a mandatory basis — with rope samples cut from the conveyance-end of an operational hoist-rope. In the present case it is seen that the difference between the %LMA chart-readings at the conveyance-rope-end and at the "worst" rope segment is some 5.0% for both the in situ and shop-floor situations. Assuming that the %LMA chart-readings are directly proportional to the corresponding 'true' LBS data, we conclude that, in the present case, a destructive test at the conveyance rope-end would underestimate the 'true' LBS by some 5.0%.

As noted by the operator (Fig. 1b), the location of the $\frac{1}{16}$ in. $\times$ 2 in. long seizing-wire rope-markers is clearly in evidence on the LF chart, but not so on the LMA trace.

In view of the negligible amount of indicated corrosion, the operator's LBS_{max} estimate was 5.0% (report #89-286J), i.e., the same quantitative value as the LMA_{max} chart-reading. We agree with the operator's report.

The Rotesco AC data

Shop-floor testing with the Rotesco AC was performed on 1989 04 03. The rope length tested was 1,620 ft. Testing started at the conveyance rope-end. The operator reported an LMA_{max} of 4.2% some 40 ft from the test-start, with a 4.0% LMA at 675 ft (Fig. 4). Applying a conversion factor of 1.77, a corresponding 7.4% LBS_{max} was estimated. The 0.0% LMA reference level was placed at the 1,550 ft tested rope-end (i.e., at the drum rope-end).

We marked the operator's test-chart (Fig. 4) with: (a) the 0.0% LMA reference level and (b) the %LMA plus %LBS (in brackets) chart-readings at the 40 ft and 675-875 ft rope sections. These readings are in agreement with the operator's reported results. So are our %LBS estimates, using the same 1.77 conversion factor as did the operator. The LMA difference between conveyance and drum rope-ends is 1.8%

The Rotescograph data

Shop-floor testing with the Rotescograph was performed on 1989 04 10. The operator's instrument chart is reproduced in Fig. 2b. The rope length tested was 1,660 ft. Testing started at the drum rope-end. The 0.0% LMA level was at this rope-end. The LMA difference between the two rope-ends was 1.0%. The operator marked the seizing-wire rope-locations — which showed up well on both the LMA and LF chart-traces — and the rope-advance footages on the strip-chart. However, only the LMA_{max} chart-reading was marked, namely: 3.6% at 1,070 ft. We agree with the operator's chart-readings, *per se*.

The operator also submitted LBS estimates. These were calculated by doubling the respective LMA chart-readings at the corresponding rope-locations.

The LMA-250 data

Shop-floor testing with the LMA-250 instrument was performed on 1989 04 04 (Fig. 3b). The rope length tested was 1,516 ft. Testing commenced at the conveyance rope-end. The 0.0% LMA was at the drum rope-end. The LMA difference between the two rope-ends was 3.5%.

The operator submitted a report, and marked the chart with: (a) the 0% LMA level, (b) the location of the seizing-wire rope-markers (these are clearer on the LF than on the LMA chart-trace), and (c) the respective (as per the report) LMA chart readings.

Moreover, the presence of broken wires at 1,130 ft and 1,336 ft from the conveyance rope-end was noted. The Magnograph operator also reported a broken wire at 1,132 ft from the conveyance rope-end, while the WBK operators reported an outer-wire break at 1,366 ft from the conveyance rope-end. Although not specifically reported by the Rotescograph operator, an LF trace perturbation indicative of a broken wire does appear at 1,360 ft from the conveyance rope-end of his instrument-chart.

The operator's report referred to a relatively "clear" LF trace, i.e., to LMA due to crown-wire wear rather than to corrosion. We agree with the operator's chart readings and report.

The WBK data

Shop-floor testing was performed on 1989 04 10 with the German WBK instrument — side-by-side with the Rotescograph test-run. The rope length tested was 1,663 ft (507 m). The strip-chart contains, reading from top-to-bottom: five LF traces, a %LMA trace, and a length indication scale (in meters). There is also space for a second %LMA trace and for a rope-diameter indication-trace (not used in the current test-series). With the sensor-head closed, the individual measuring coils LF #1 and LF#2 were joined together, and so were #3 and #4. The fifth LF chart-trace summarizes the output of these two individual traces. Surface defects were particularly conspicuous on this instrument's LF traces.

The two WBK operators carefully annotated their charts, including some LMA readings and the seizing-wire marker (M1 to M6) locations. They also submitted a report. Testing commenced at the drum rope-end. The LMA difference between the two rope-ends was 2.3%.

We did not receive a copy of the complete strip-chart. Instead copies of the important chart sections were submitted, numbered Figures 1.1 to 1.13, inclusive. We reproduce these as our Fig. 5. As may be seen, the 0.0% LMA reference level was set along the 0m–2m rope section at the drum rope-end, and the %LMA scale was 0.663% per mm of full-scale diagram ('Fig. 1.1' of our Fig. 5).

The German report included a tabulation of the M1 to M6 marker locations. It is interesting to note that the tabulated distances between these markers was consistently 76 m (249.3 ft). The corresponding 'true' distance was 250 ft. We agree with the operators' report.

DESTRUCTIVE TESTING

Two 16-ft samples were cut from our rope #1 for destructive testing. From these, contiguous samples, each 8-ft long, were used for destructive testing, and for external and internal visual inspection. Results of the latter work are not yet available.

The general test procedure has been described and illustrated elsewhere (6).

The samples for destructive testing were designated as samples #1a, and #1b. With reference to Fig. 1b:

Sample #1a: cut from the drum rope-end at the 'Mk 1250 pi' marker, i.e., from the rope section containing an LMA chart-reading of 0.0% (Fig. 1b);

Sample #1b: cut from the 500-516 ft rope segment, i.e., from the rope section containing an LMA chart-reading of 5.5% (Fig. 1b).

Destructive testing was performed in the laboratories of Wire Rope Industries (WRI) Ltd., at Pointe Claire, Quebec. Standard procedures were followed, as monitored by Messrs. G. Rousseau (of CANMET) and R. Boles (of WRI).

As mentioned before, records of the original breaking strength of our rope #1 were unobtainable. We knew, however, that similar hoist-ropes broke at 84,250 lb to 125,000 lb. when new (1). *Faute de mieux*, we decided to designate the 96,500 lb breaking strength of our own sample #1a as the "original" rope breaking-strength.

Our destructive test results were as follows:

Sample #1a: 96,500 lb, i.e., a loss of 0.0% of the assumed "original" 96,500 lb strength, at a point where the maximum LMA chart reading is 0.0% (Fig. 1b). Sample diameter was 1.040 in.;

Sample #1b: 94,000 lb, i.e., a loss of 2.6% of the assumed "original" 96,500 lb strength, at a point where the maximum LMA chart reading is 5.5% (Fig. 1b). Sample diameter was 1.020 in.

The conditions of the broken samples are illustrated in Figures 6 and 7. These were as follows:

Sample #1a: three strands broke approximately one ft from the cone. No wear, and good lubrication, were visible;

Sample #1b: four strands broke approximately one ft from the cone. There was heavy wear on the outer wires, and rust throughout the rope. Breaks were tensile-failures, and shear-failures, in a ratio of some 50/50.

The 'true' LBS on the basis of the destructive test on sample #1b was of the order of magnitude as estimated by the EM instrument operators. However, the original rope breaking-strength could, unfortunately, only be guessed at.

ANALYSIS OF TEST RESULTS

(1) Tested rope lengths and general comments

We tabulated the in situ chart-readings in Table 1a, and the shop-floor ones in Table 1b. Details of all relevant test set-ups are listed in Table 2. Considering the influence of instrument calibration-procedures upon the test-results, we included some relevant information in Tables 1a and 1b, such as: (a) the rope-end at which calibration was effected, (b) the rope-end at which 0.0%LMA was found to be, and (c) the %LMA difference between the two rope-ends.

We were not present at the in situ tests. We cannot, therefore, explain why the tested rope length was so much more in case of the Rotescograph than it was in case of the Magnograph and LMA-250 (Table 1a). Considering both the in situ and shop-floor tested rope-lengths, it seems likely that the Rotescograph value is in error.

We are also unable to explain why the 1.000 in. diameter rope should have been referred to as an 18×7 construction in the field, and then found to be a 6×27 stranded rope on the shop-floor.

On the shop-floor too, the difference between the various tested rope-lengths is unacceptably large (Table 1b). In this case, though, the presence of the seizing-wire rope-markers makes it easier to pin-point the missing rope-sections either at the start, or end, of the test-runs. The worst situation, at both conveyance and drum rope-ends, was noted in case of the Magnograph strip-chart (Fig. 1b). These rope-markers are also very helpful in providing accurately located "fingerprints" for comparing the respective %LMA chart readings of the various EM instruments.

Wherever we were unable to reproduce the strip-charts in a single length, we provided match-marks (such as: ref. 'A'; ref. 'B'; etc.) on the individual chart-segments. Moreover, we added to all charts: (a) the 100% reference levels, (b) the relevant sensitivity scales (%LMA per major chart-division), and (c) the %LMA chart-readings at the most important rope-locations.

(2) LF chart-readings:

Broken wires showed up fairly consistently on the LF-traces of all the instruments. The WBK traces were particularly explicit in case of surface flaws.

(3) Repeatability: LMA chart readings

The in situ LMA chart-readings are, on the whole, in fair agreement. Quantitatively the readings are rather low. There would be little, or no, concern as to this rope's further operational use.

Unfortunately, there were few natural "fingerprints" by means of which to positively identify, and compare, the in situ and shop-floor chart-traces. The one close to the conveyance rope-end — we marked it as point 'X' — does, however, appear to be fairly conspicuous on both the in situ and shop-floor charts. This suggests that we are, indeed, dealing with one and the same rope in both cases.

Comparative evaluation of the five EM instruments used during the shop-floor tests can best be based on the LMA chart-readings (Table 1b) obtained at: (1) point 'X', and (2) the six seizing-wire rope-marker locations M1 to M6. These markers consisted of $\frac{1}{16}$ in. diameter wire, wound around the 1.000 in. rope at 250 ft intervals along 2 in. stretches. Noting that the metallic cross-sectional area (A) of the rope itself was assumed to be 0.4578 in.^{2}, addition of the seizing-wire represented a metallic area increase of some 35%. It will be noted that in Table 1b we listed both the %LMA chart-readings, and the height of the LF trace perturbations, at these markers. We referred to them as 'LMA' and '(spike)', respectively. The 'spikes' on the WBK chart-traces are particularly noticeable.

In this context, though, we must also refer to the different quantitative resolutions of the five instruments, exemplified, as an example for the Magnograph, by Fig. 32c in ref. 5.

(4) LBS estimates

Since we had no reliable information about the rope's original breaking-strength, we had no way of checking the accuracy of the operators' LBS estimates. On the basis of the destructive test-result obtained with sample #1b, and designating the strength of sample #1a as the benchmark value, it would appear that the estimates were of the right order of magnitude.

(5) Comparability: in situ vs shop-floor test results

The LMA chart-readings in Tables 1a and 1b are in fair agreement. While this is in line with our previously stipulated contention (11) that in situ and reel-to-reel EM tests can be legitimately compared, we must repeat the *caveat* of not being 100% certain that the field and shop-tests were undertaken on one and the same rope.

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APPENDIX 1

Tables 1 and 2

as well as Figures 1 to 5, inclusive

Table 1a

In situ tests — %LMA chart readings and related data

Subject	Magnograph Fig. 1a 1988 09 09	LMA-250 Fig. 3a 1988 09 09	Rotescograph Fig. 2a 1988 09 15
Tested rope length (ft)	1,317	1,290	1,940+120= 2,060
Instr. calibr. at	conv. end	drum-end	conv. end
0.0% LMA at	conv. end	conv. end	drum-end
Overall LMA_{max}: percent ft, from conv. rope-end	4.5% 954	4.8% 822	3.9% 1,115
LMA at pt. 'X': percent ft, from conv. rope-end	3.3% 88	3.0% 108	3.0% 42
%LMA difference between two rope-ends	1.7%	0.8%	0.6%

Table 1b

Shop-floor tests — %LMA chart readings and related data

Subject	Magnograph Fig. 1b 1989 04 04	LMA-250 Fig. 3b 1989 04 04	Rotescograph Fig. 2b 1989 04 10	Rotesco AC Fig. 4 1989 04 03	WBK Fig. 5 1989 04 10
Tested rope length (ft)	1,449	1,516	1,660	1,610	1,663
Dist. of first/last marker, to:					
conv. rope-end (ft)	54	228	240	240	236
drum rope-end (ft)	57	62	178	185	177
Instr. calibr. at	conv. end	conv. end	drum-end	conv. end	drum-end
0.0% LMA at	drum-end	drum-end	drum-end	drum-end	drum-end
$\underline{LMA_{max}}$:					
overall	5.5%	7.9%	3.7%	4.3%	6.6%
ft, from conv. rope-end	750	50	1,180	40	35
between M3 & M4:	5.5%	4.9%	3.6%	3.8%	6.0%
LMA reading:					
at point 'X'	5.0%	7.9%	3.2%	4.4%	6.6%
ft, from conv. rope-end	54	50	60	45	56
at M1*; LMA & (spike)	3.0% (**)	5.0% (3.6%)	2.5% (1.2%)	2.5% (0.3%)	4.0% (9.6%)
at M2; LMA & (spike)	3.4% (**)	3.9% (***)	2.6% (1.1%)	2.6% (0.2%)	4.3% (9.9%)
at M3; LMA & (spike)	4.8% (**)	4.5% (***)	3.4% (1.0%)	3.6% (0.4%)	6.0% (9.9%)
at M4; LMA & (spike)	4.5% (**)	3.1% (***)	2.9% (1.0%)	3.1% (0.4%)	— (—)
at M5; LMA & (spike)	0.9% (**)	1.1% (***)	1.4% (0.9%)	0.8% (0.4%)	2.0% (9.3%)
at M6; LMA & (spike)	0.0% (**)	0.6% (***)	0.1% (0.9%)	0.2% (0.8%)	0.0% (8.6%)
%LMA difference between two rope-ends	0.5%	2.6%	1.0%	1.8%	2.3%

*: closest marker to conveyance rope-end

**: unreadable on LMA chart; clear on LF chart

***: meaningless values; recorder pen off chart

Table 2

Details of EM testing of the 1.000 in., H.R.

Item No.	Test Instr.	Test No.	Test date	Test location	Instr. operator*	Test chart: Fig. #
1	Magnograph	#88-433	1988 09 09	in situ	(2)	1a
2	LMA-250	—	1988 09 09	in situ	(3)	3a
3	Rotescograph	SQR-5	1988 09 15	in situ	(1)	2a
4	Magnograph	#89-286J	1989 04 04	shop-floor	(2)	1b
5	LMA-250	—	1989 04 04	shop-floor	(5)	3b
6	Rotescograph	ME-0003RPN	1989 04 10	shop-floor	(6)	2b
7	Rotesco AC	—	1989 04 03	shop-floor	(4)	4
8	WBK	—	1989 04 10	shop-floor	(7)	5

*: (1), (3), and (7): instr. designer/maker and service company

(2) service company

(4) and (6): mining company

(5) government organization

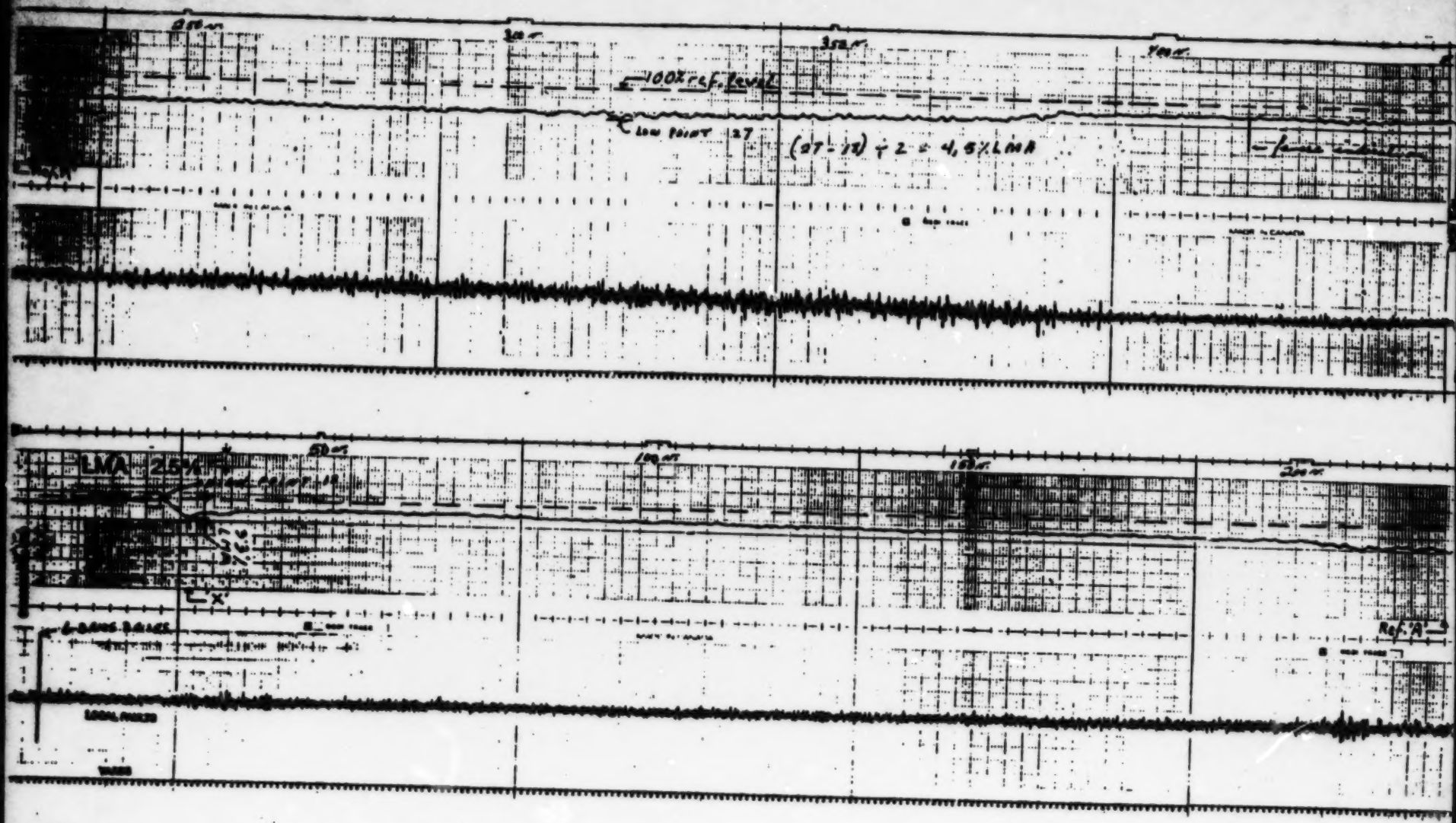

Fig. 1a — Magnograph, in situ chart of 1988 09 09

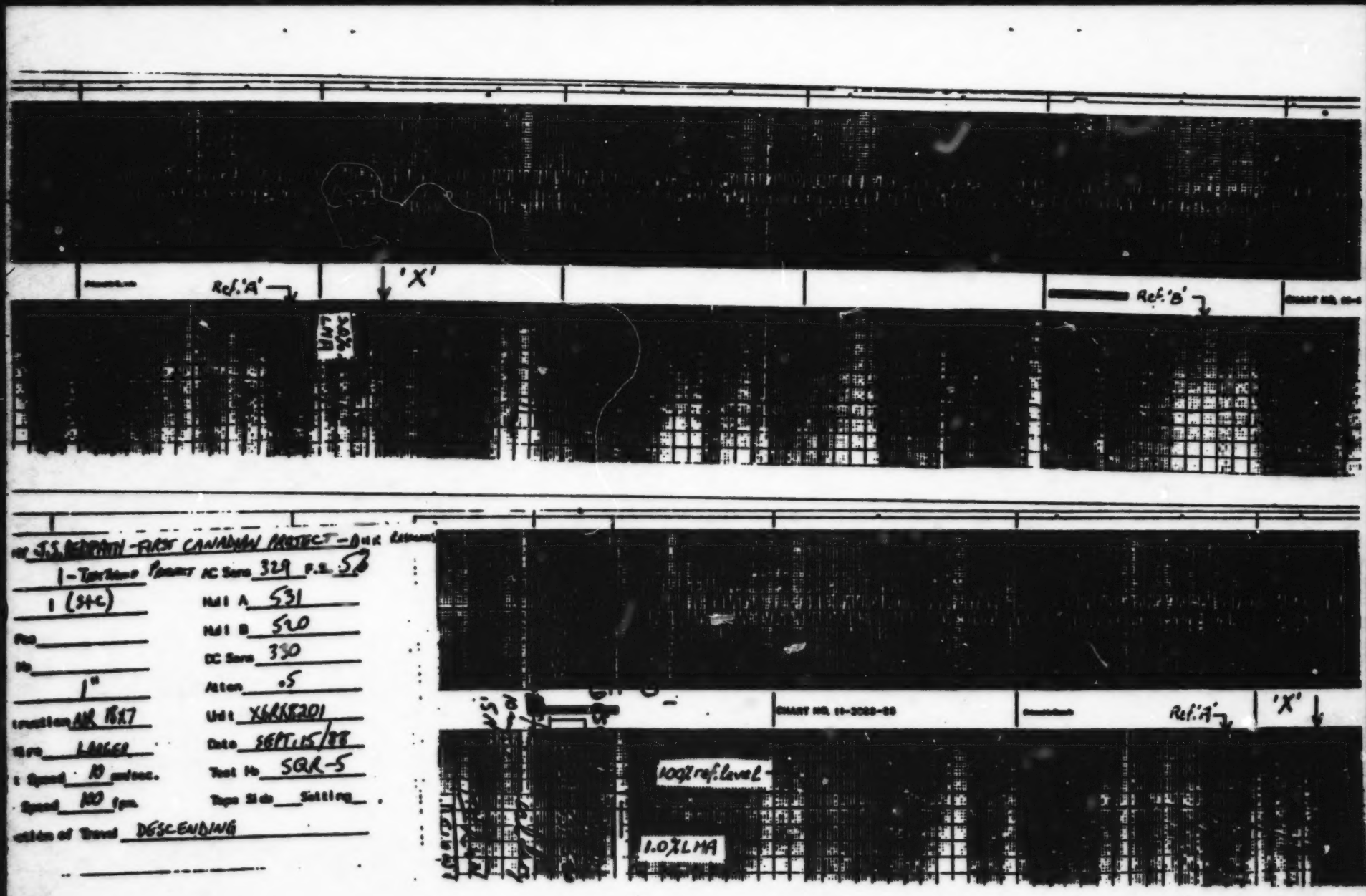

Fig. 2a — Rotescograph, in situ chart of 1988 09 15

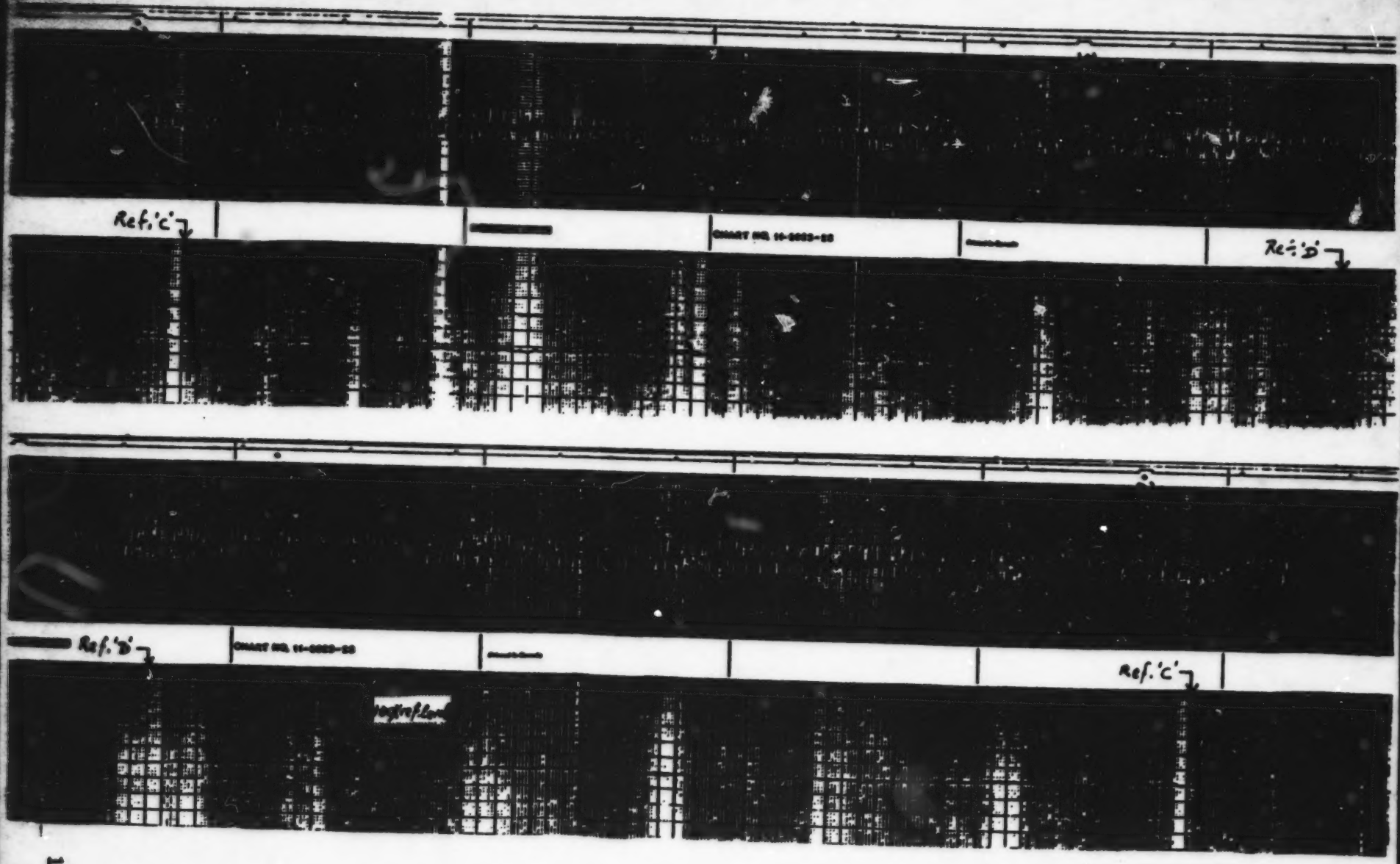

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

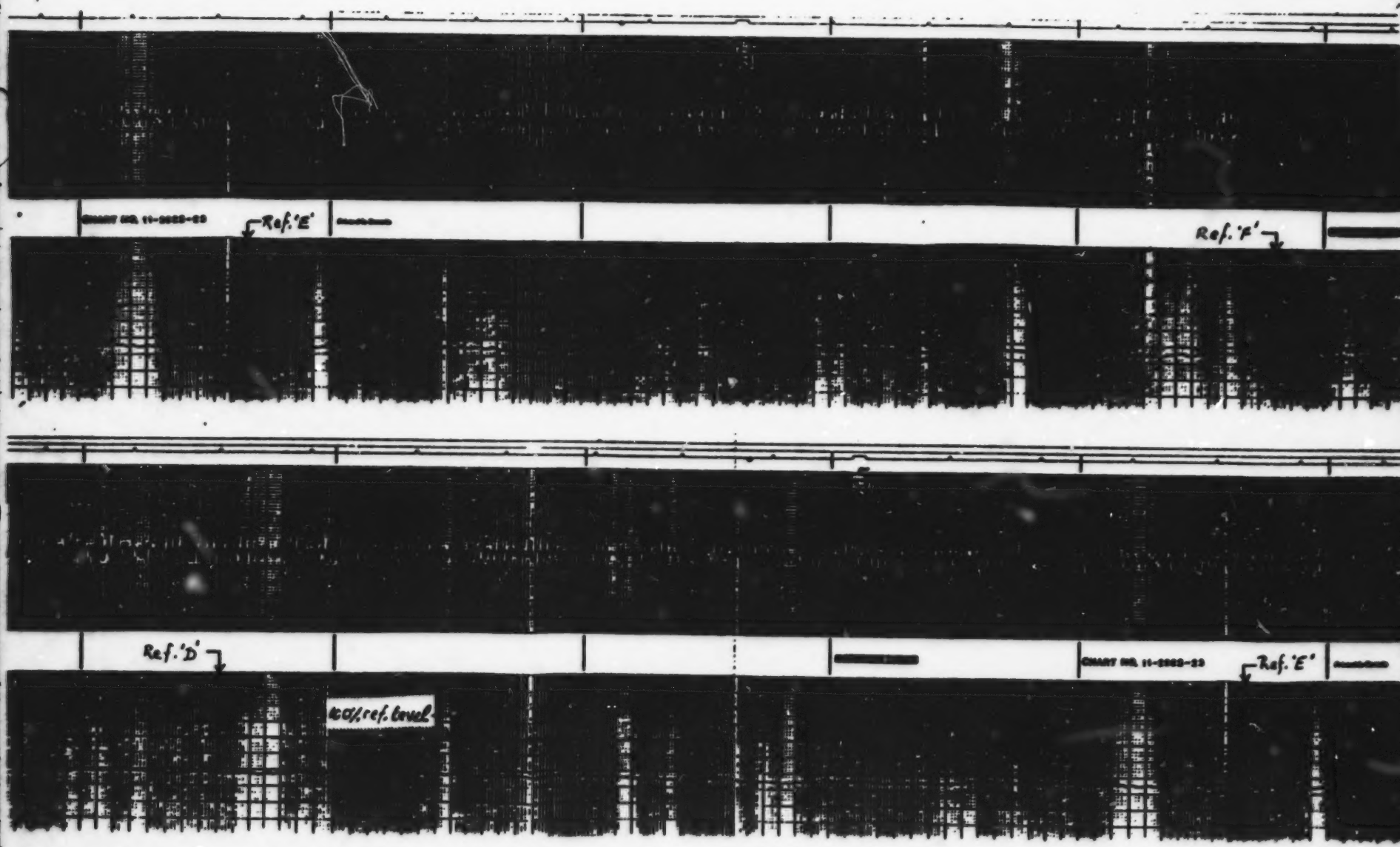

Fig. 2a (continued) — Rotescograph, in situ chart of 1968 09 15

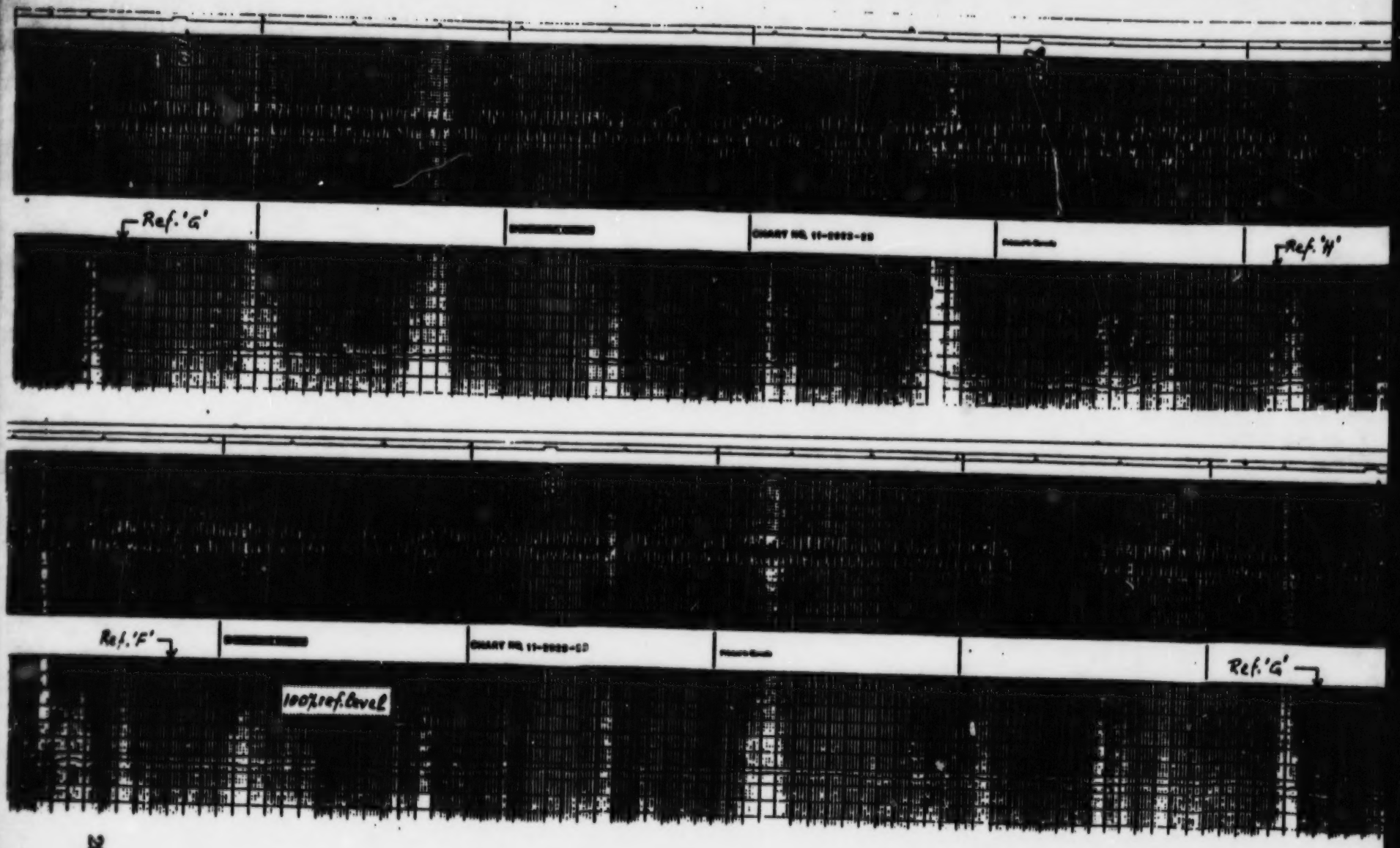

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

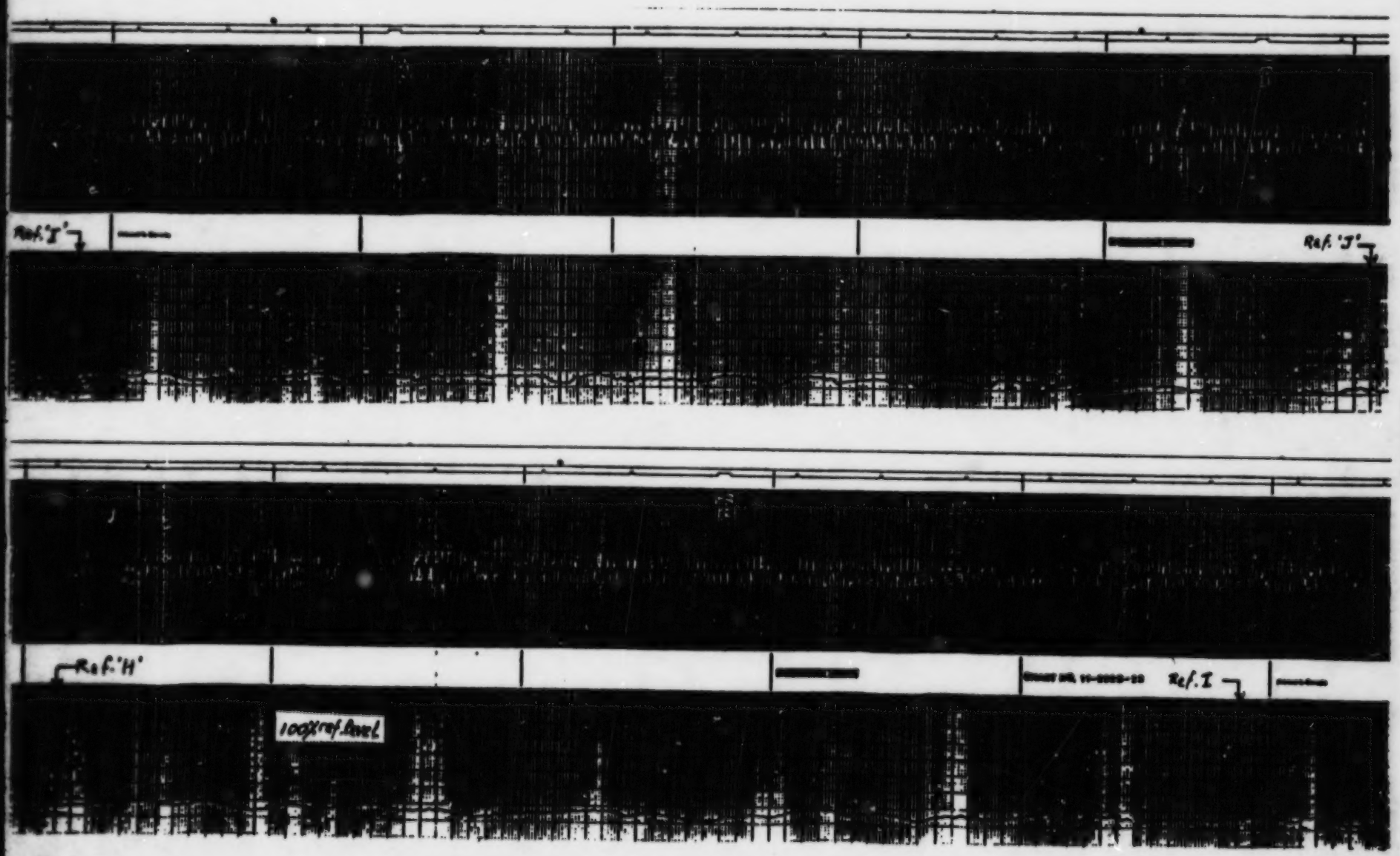

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

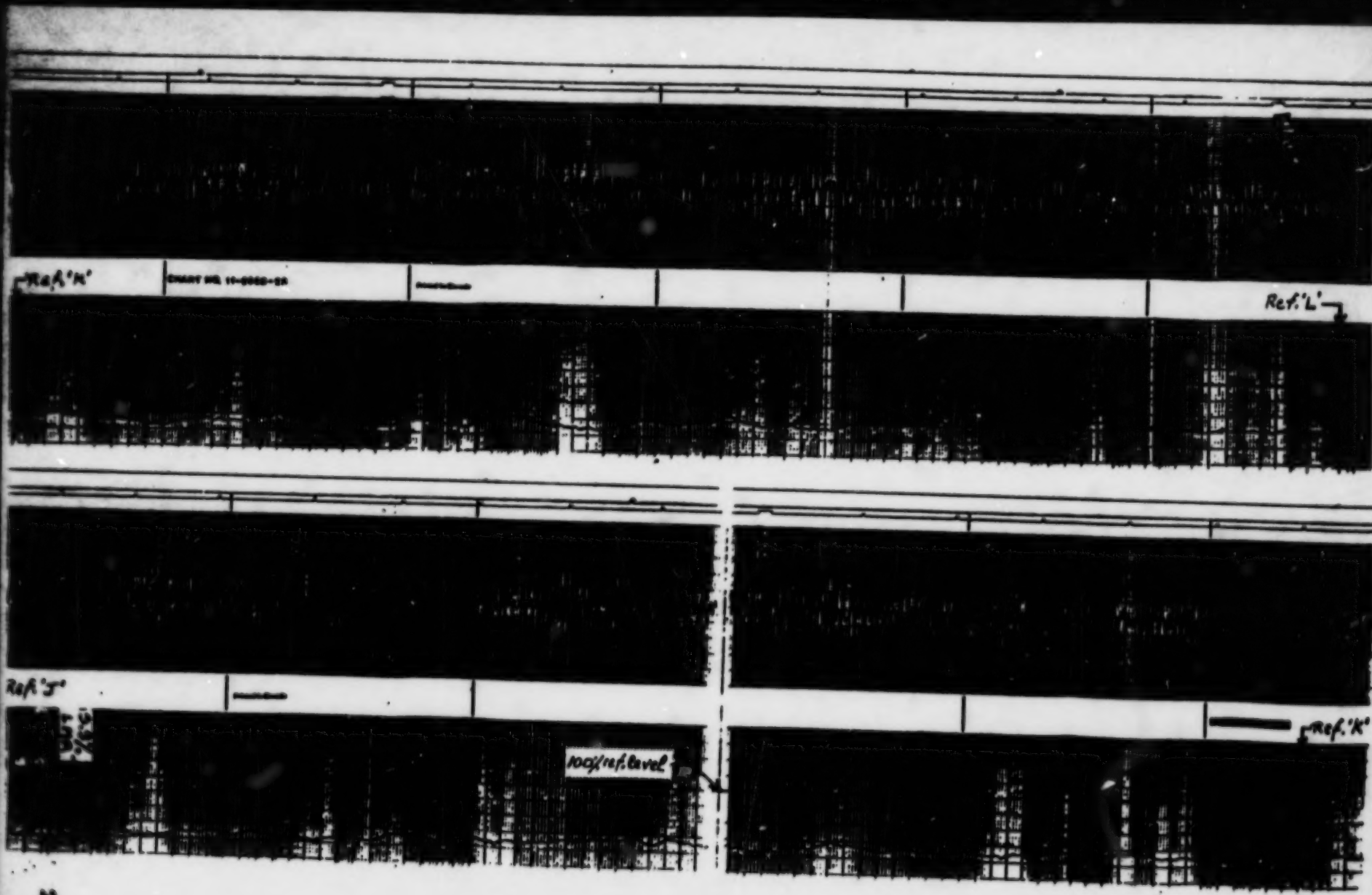

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

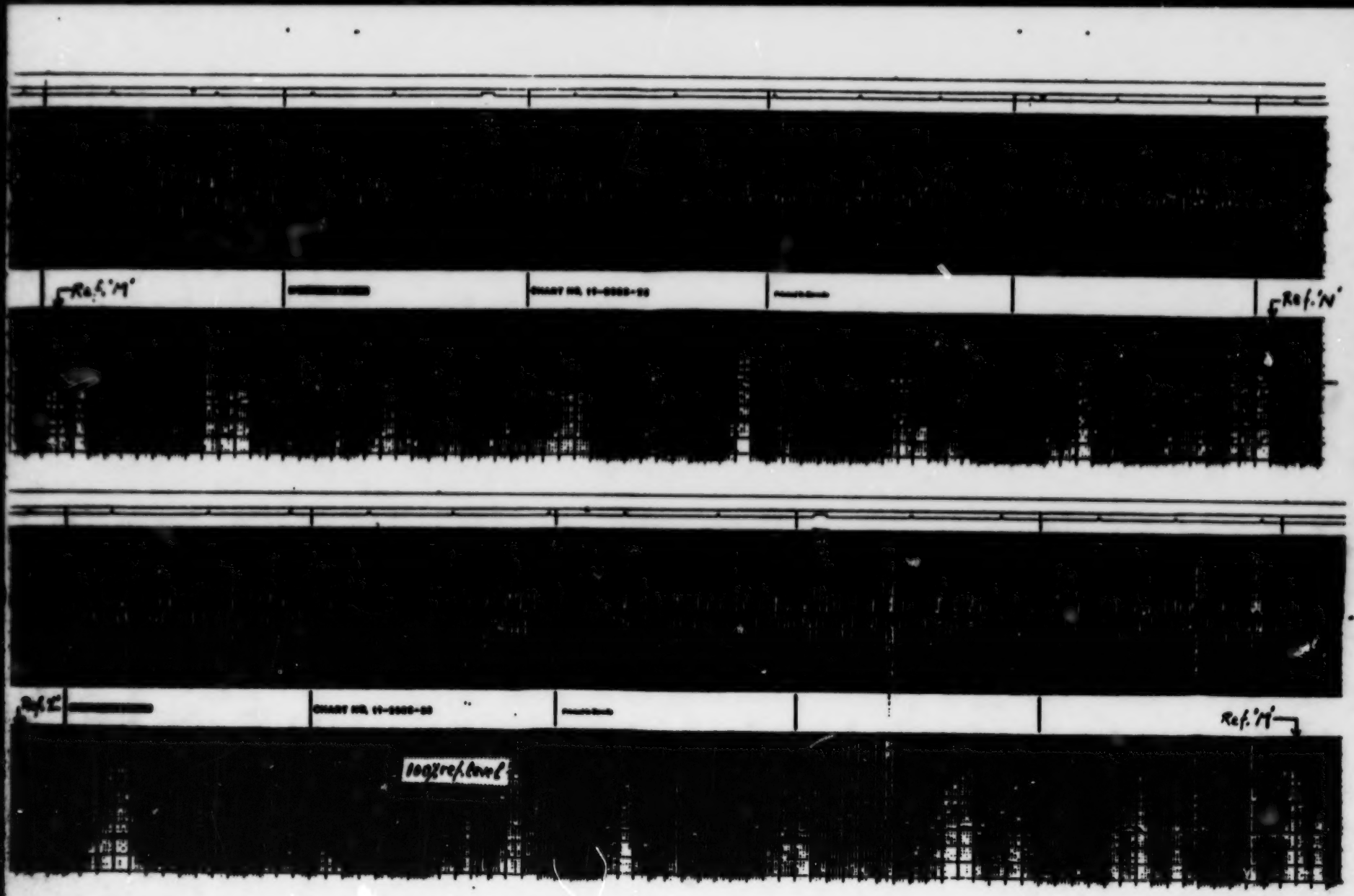

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

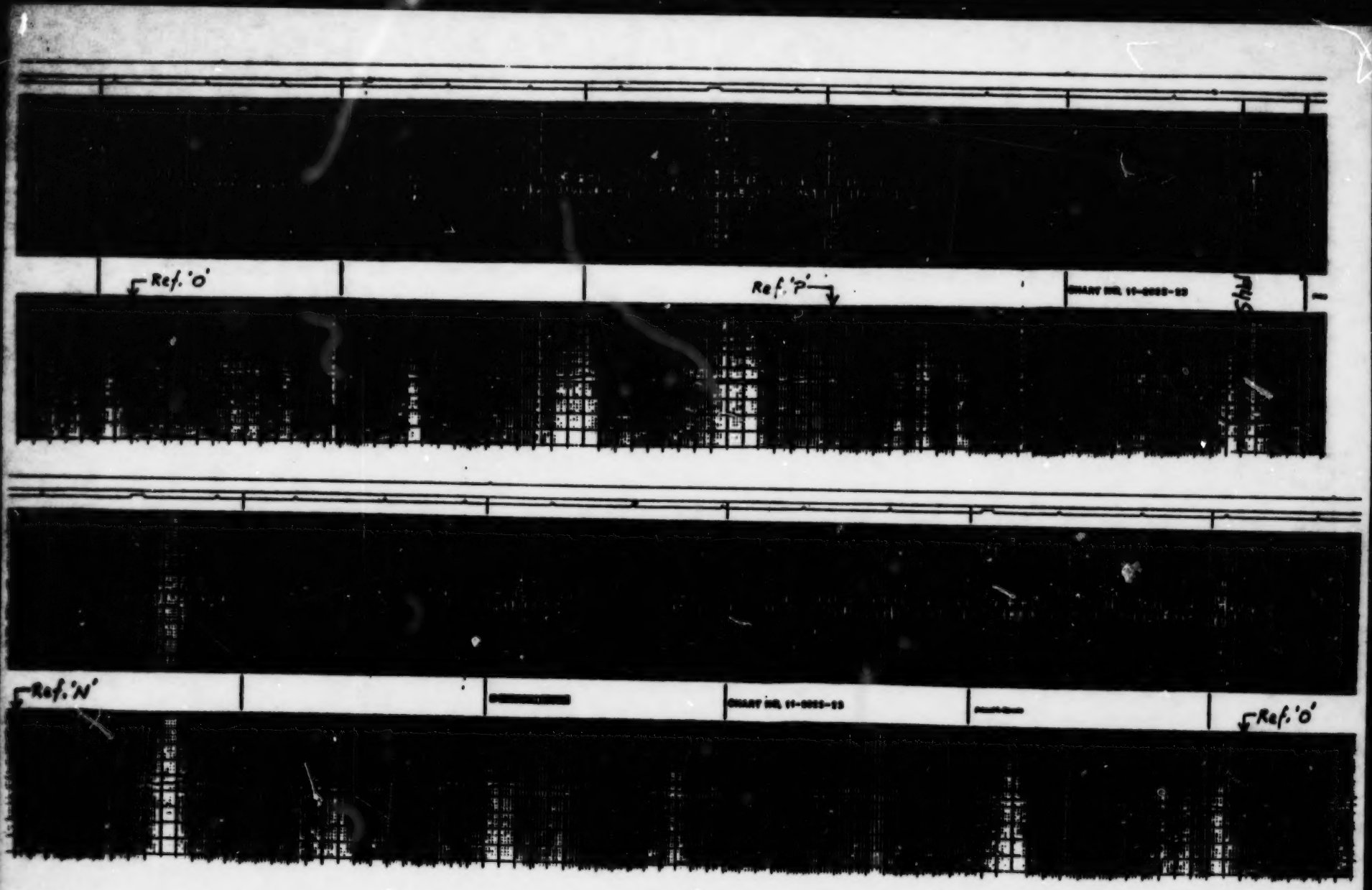

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

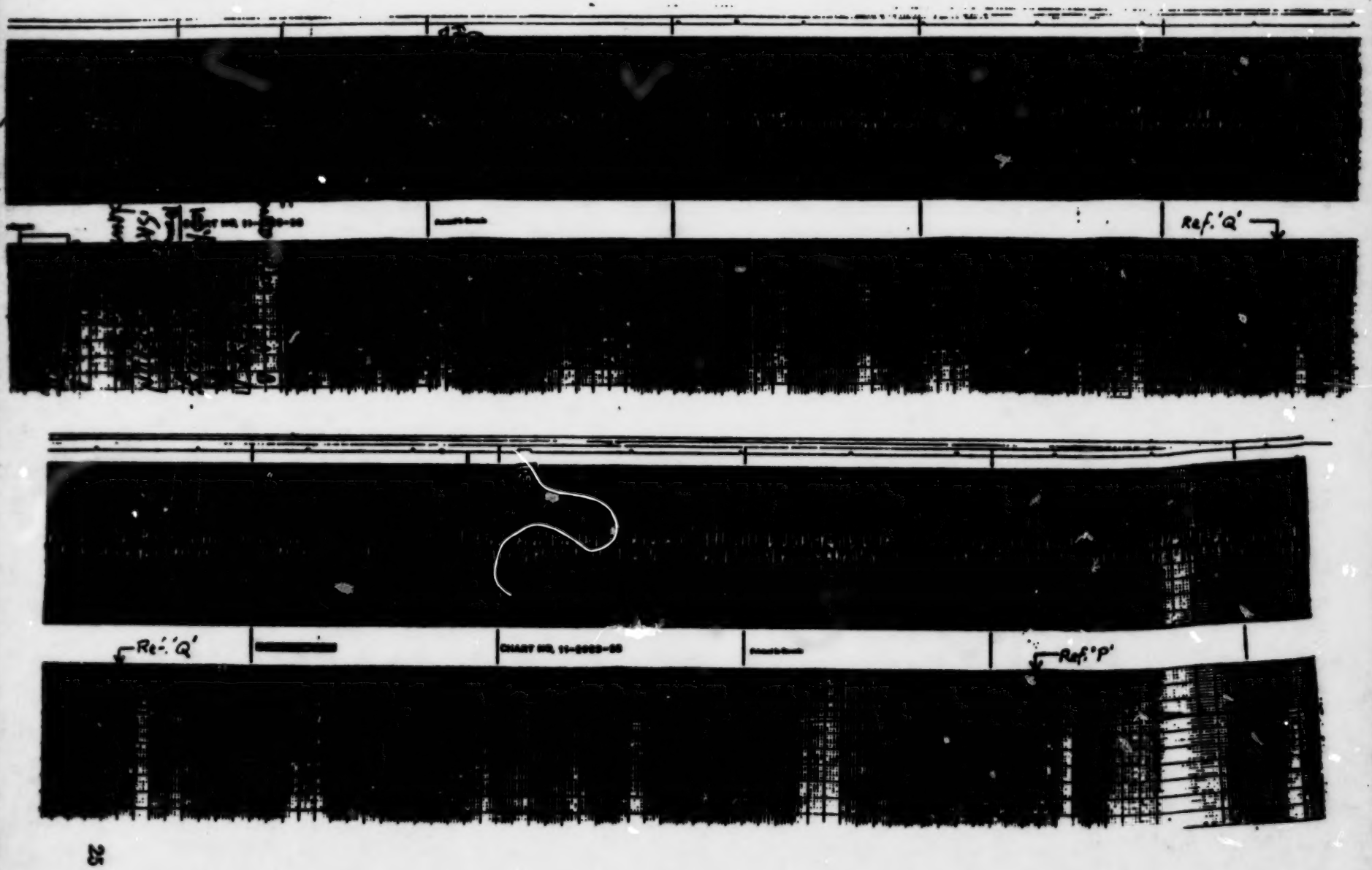

Fig. 2a (continued) — Rotescograph, in situ chart of 1988 09 15

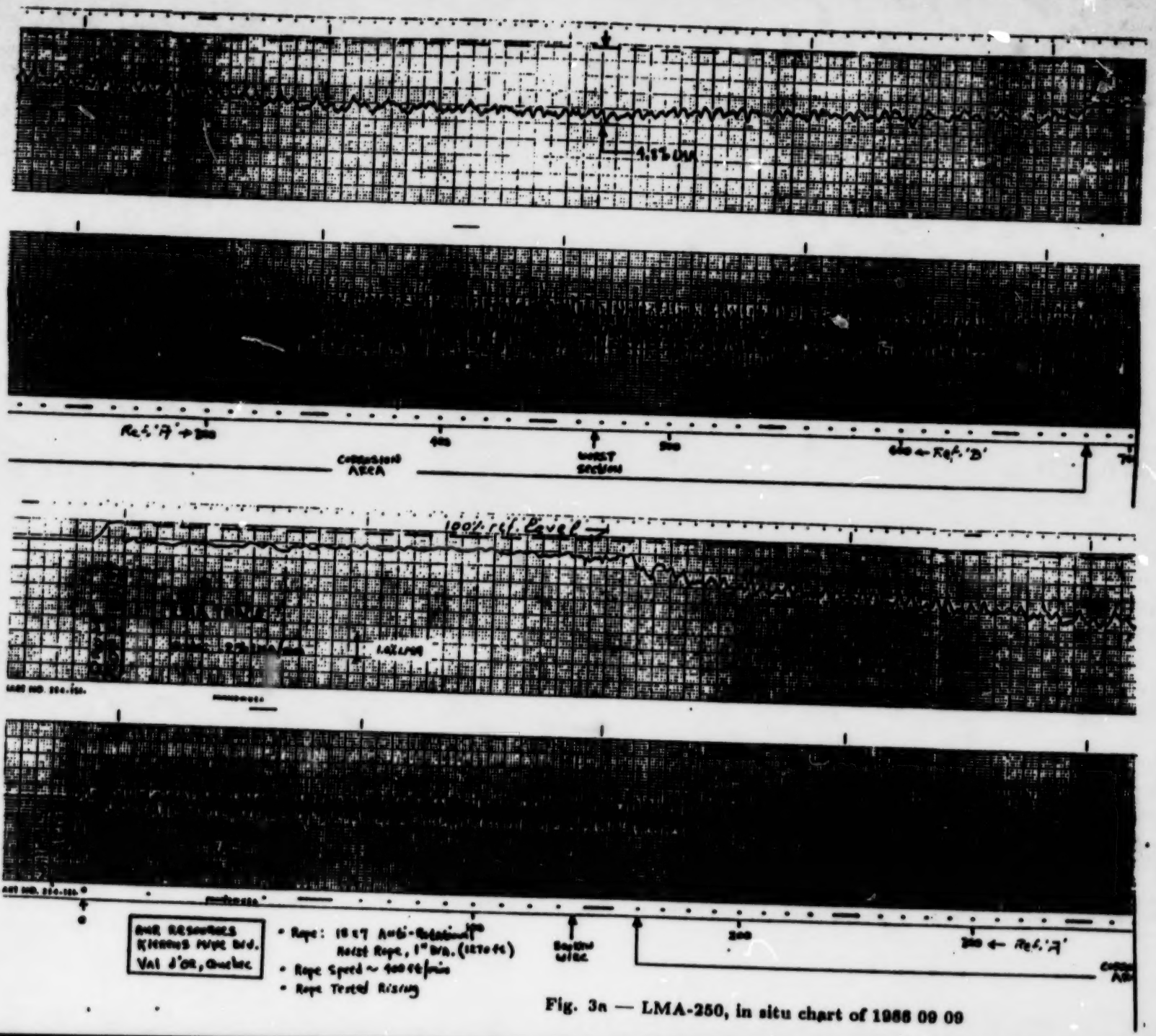

Fig. 3a — LMA-250, in situ chart of 1988 09 09

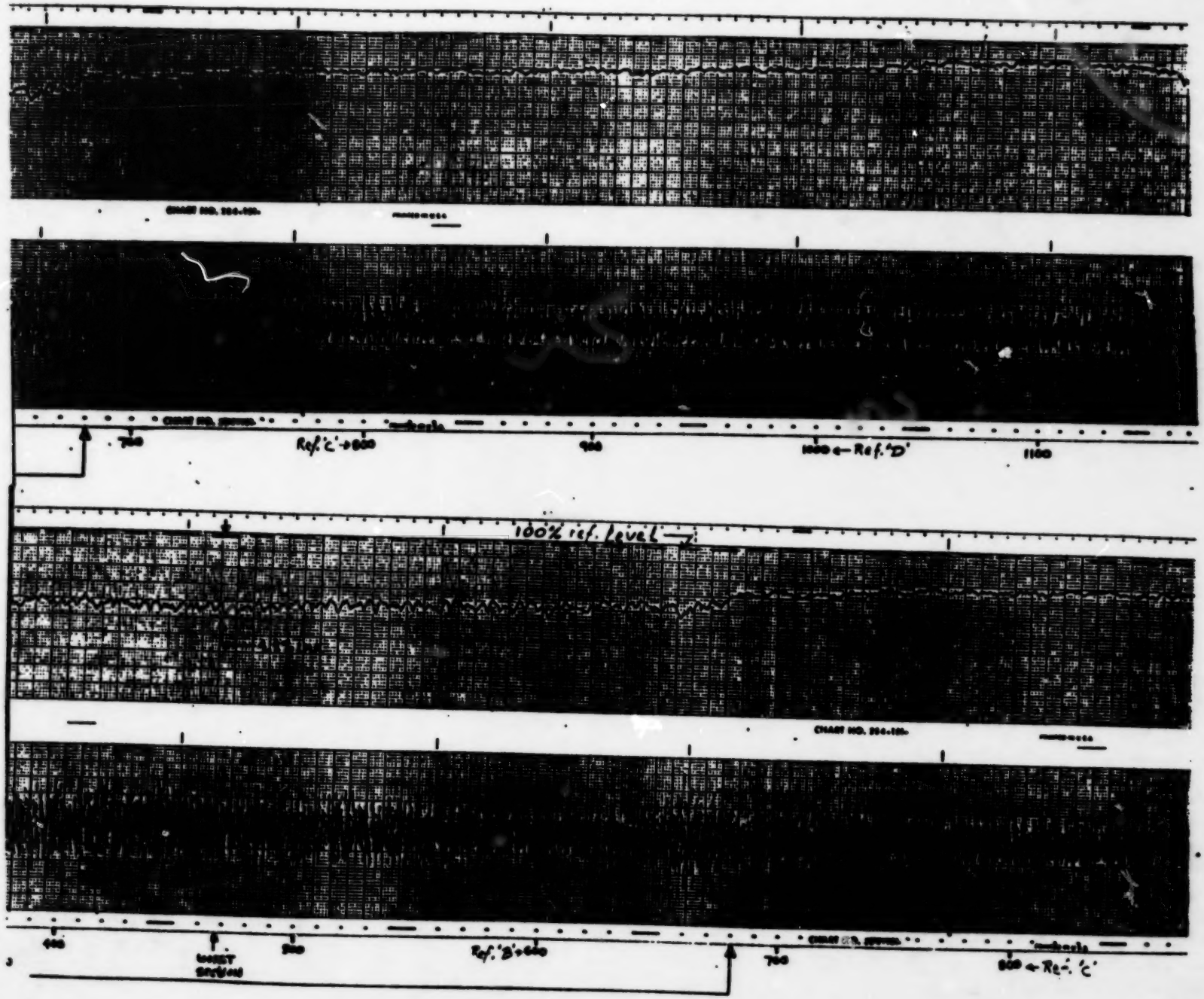

Fig. 3a (continued) — LMA-250, in situ chart of 1988 09 09

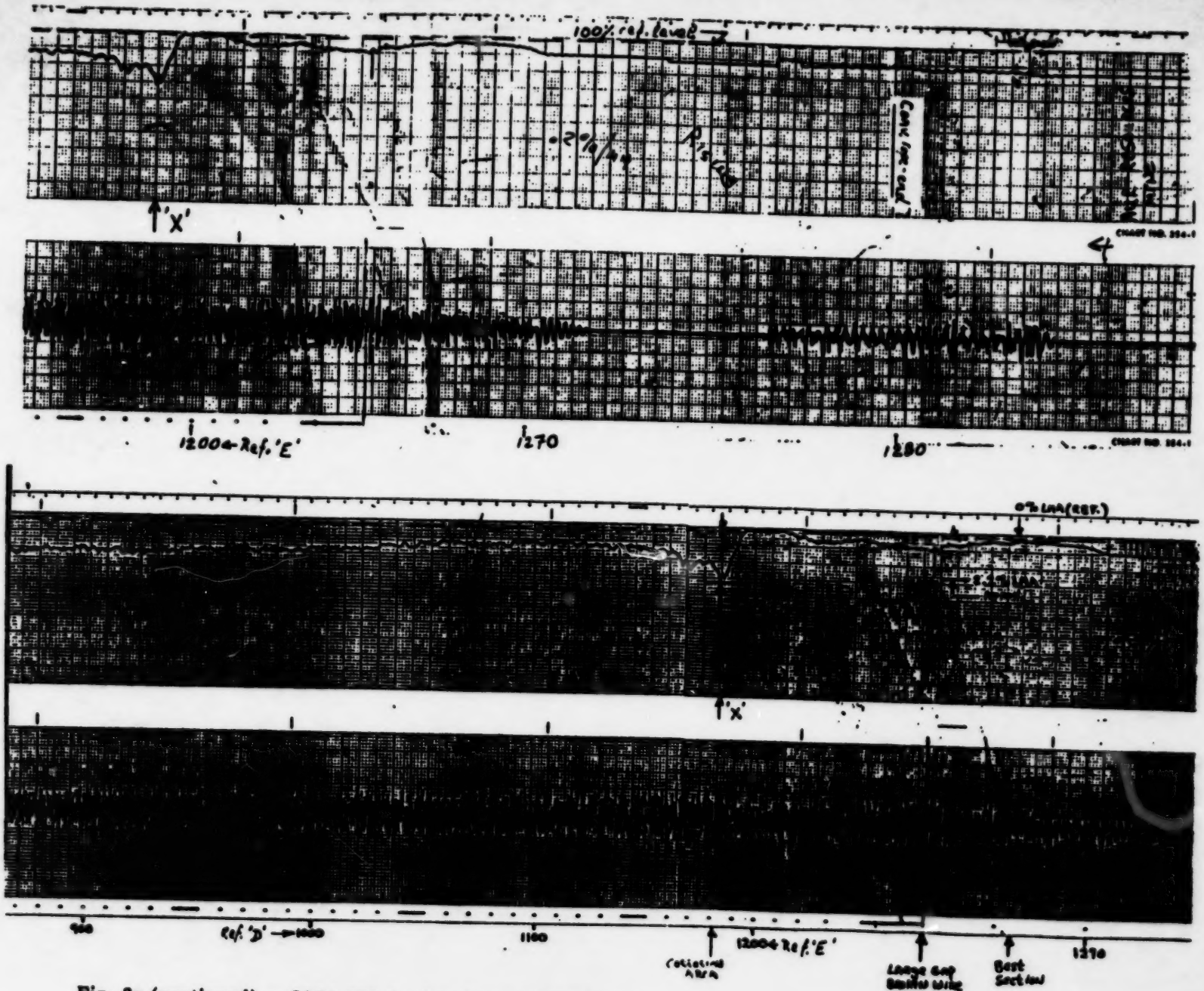

Fig. 3a (continued) — LMA-250, in situ chart of 1988 09 09

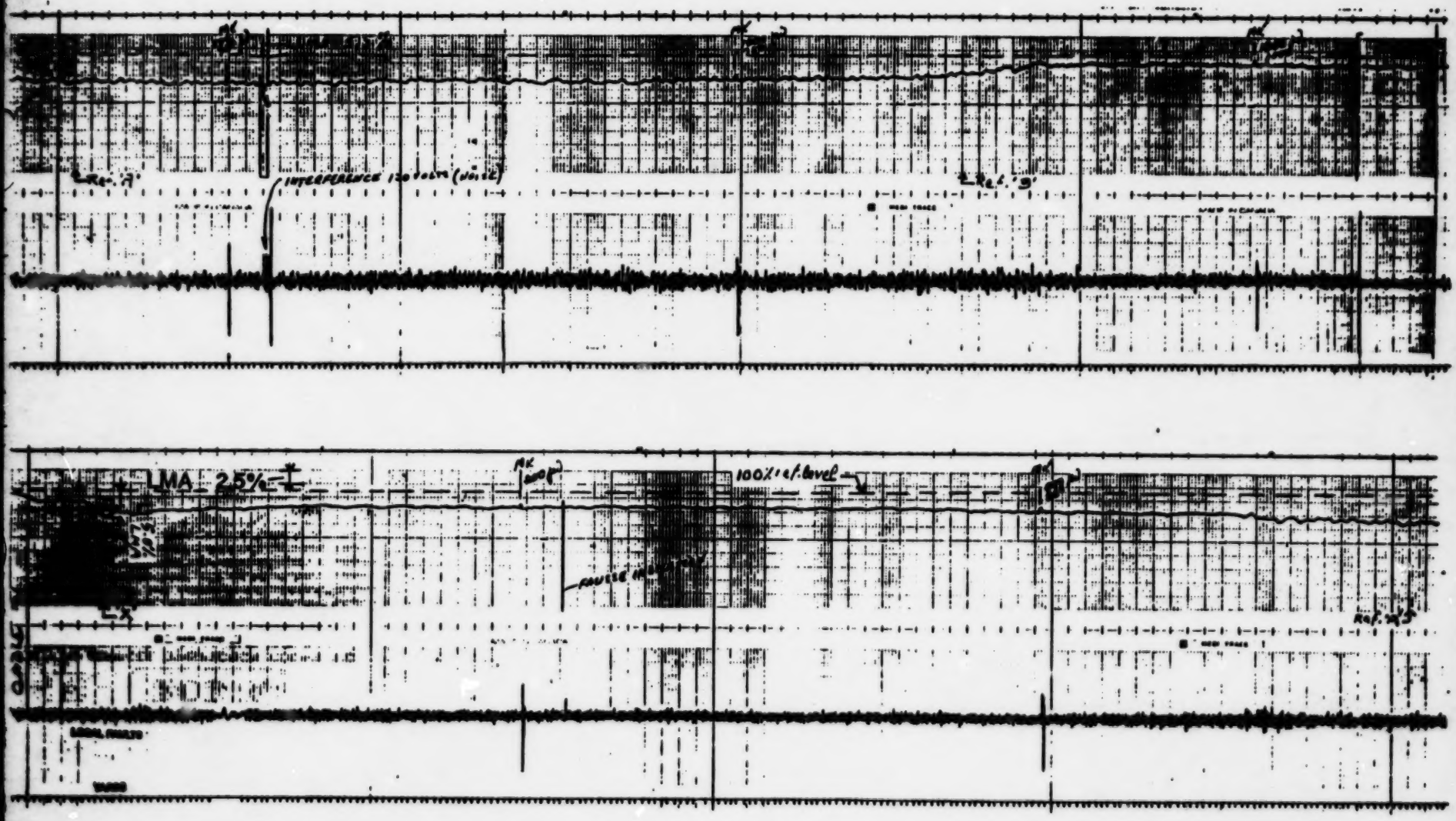

Fig. 1b — Magnograph, shop-floor chart of 1989 04 04

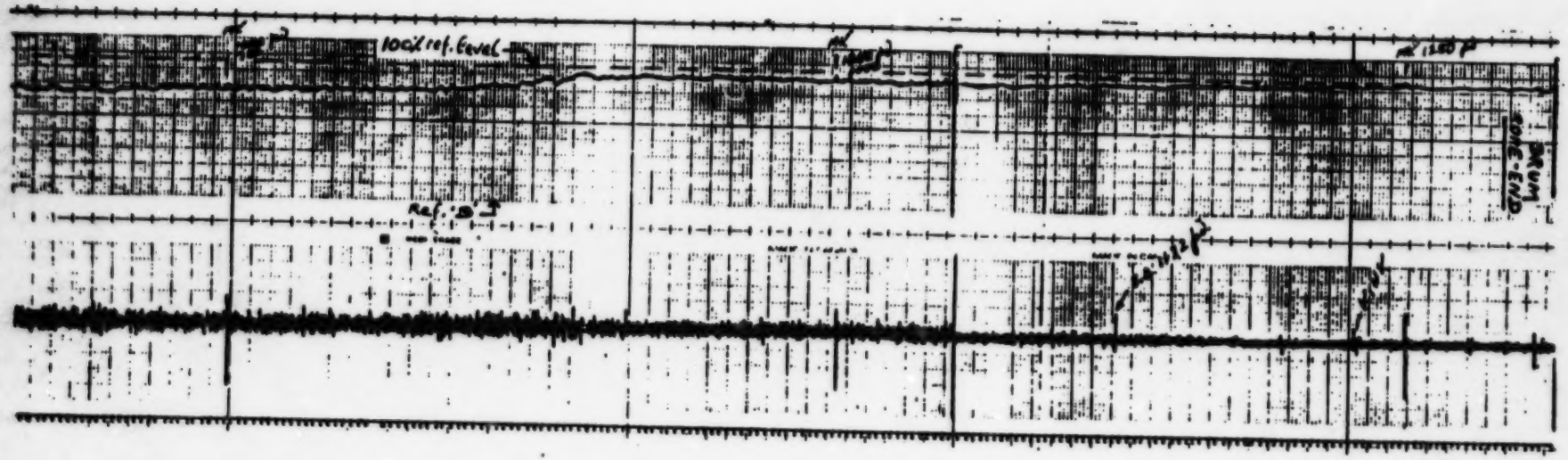

Fig. 1b (continued) — Magnograph, shop-floor chart of 1989 04 04

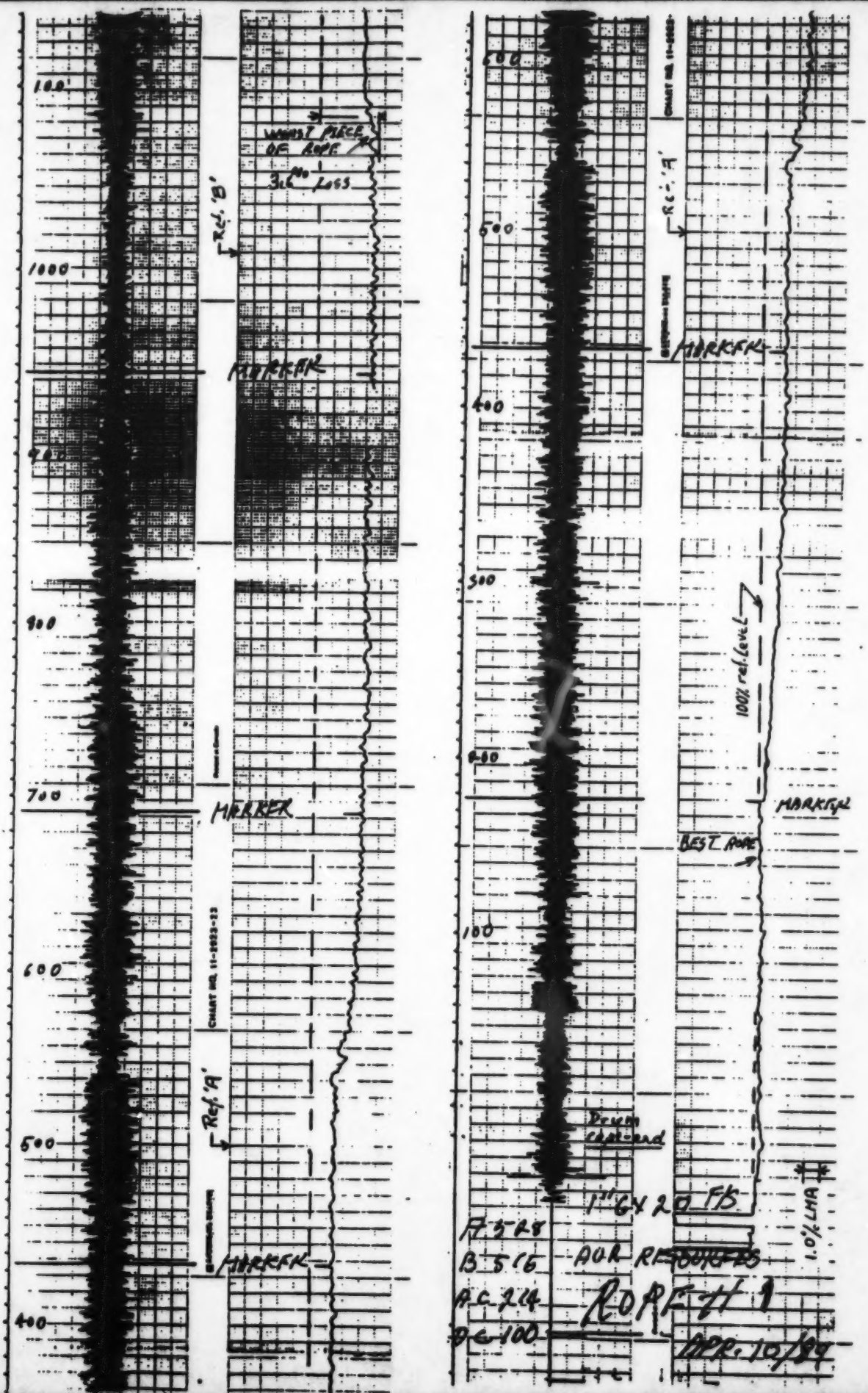

Fig. 2b — Rotescograph, shop-floor chart of 1989 04 10

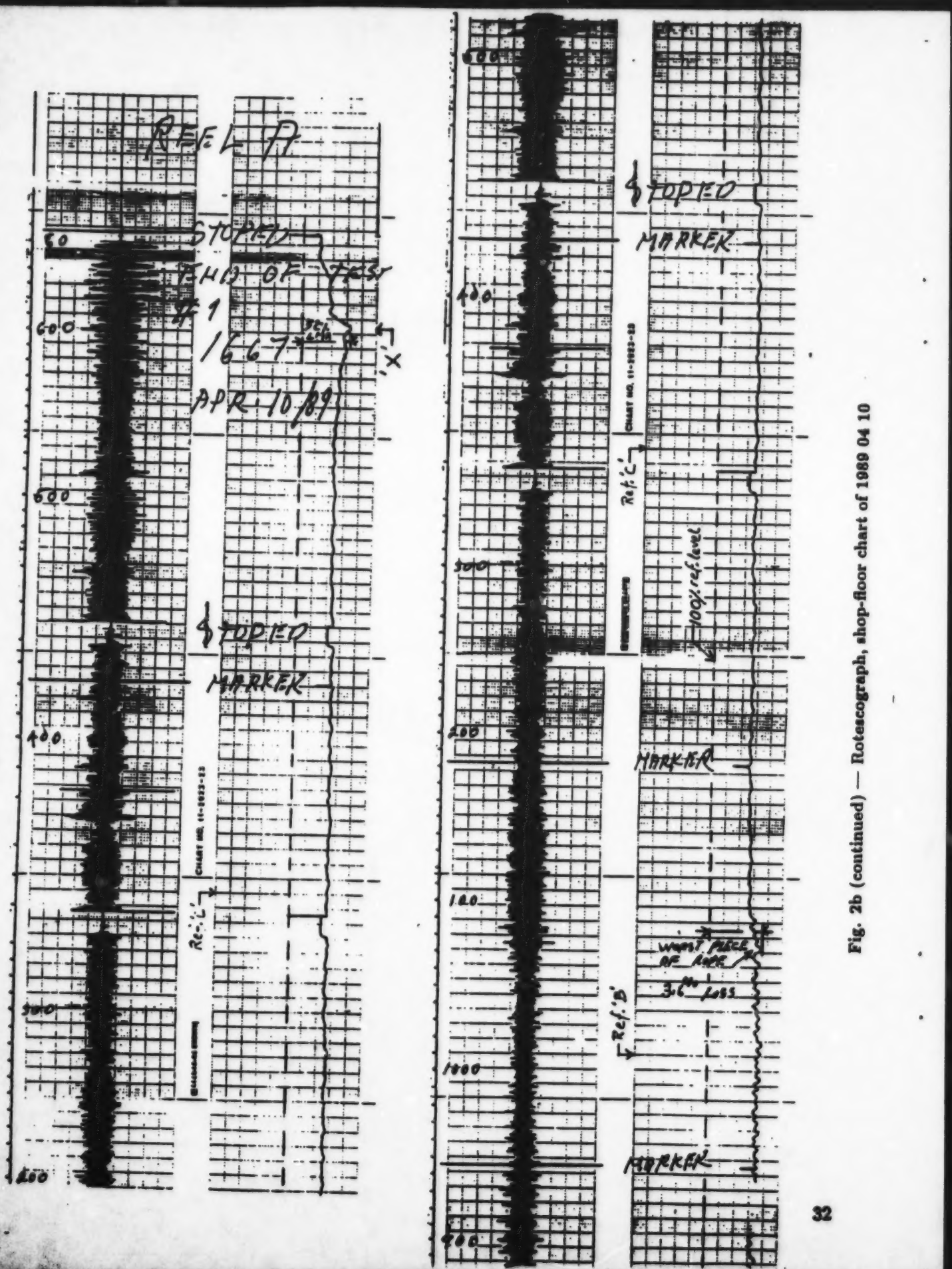

Fig. 2b (continued) — Rotescograph, shop-floor chart of 1989 04 10

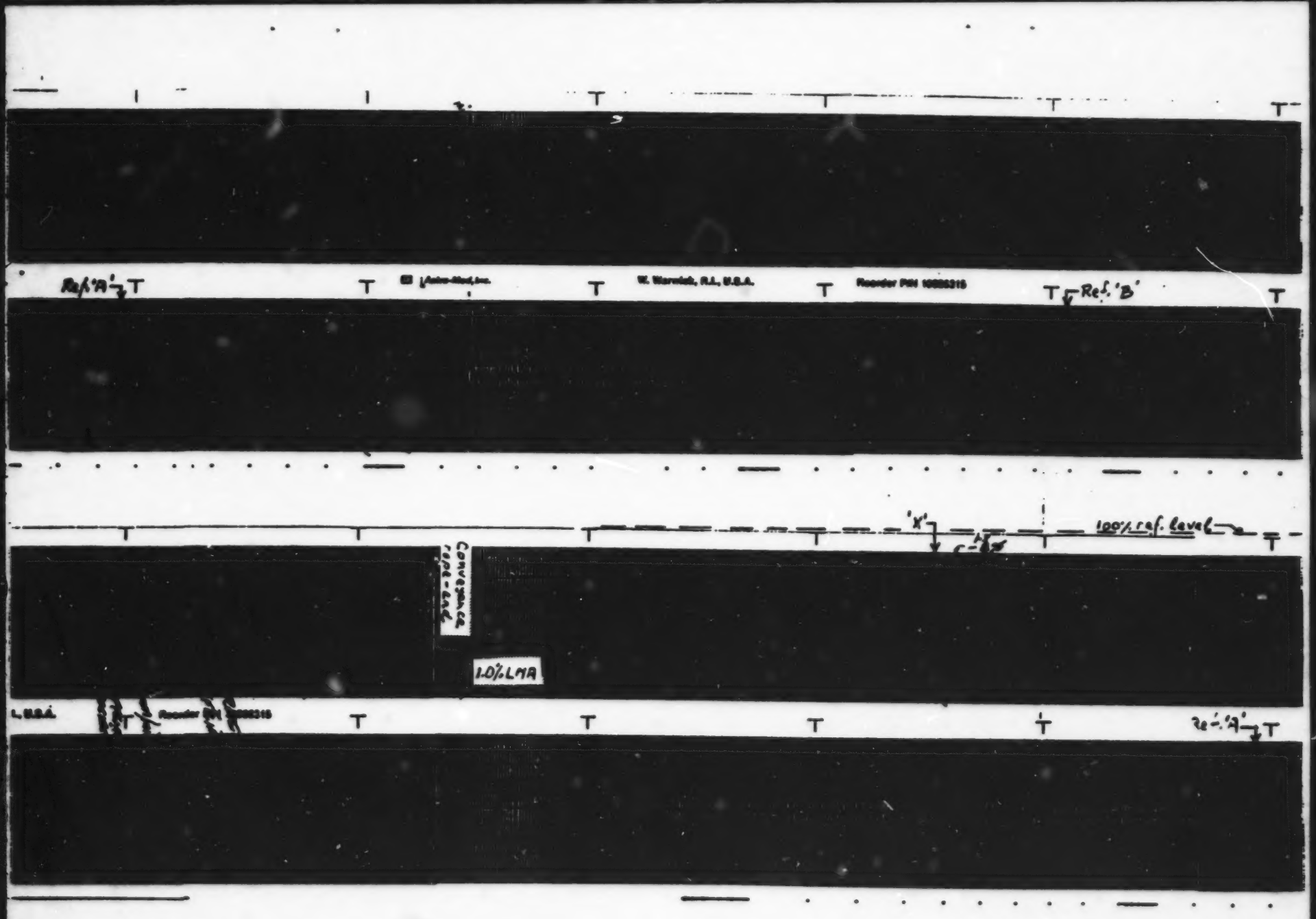

Fig. 3b — LMA-250, shop-floor chart of 1989 04 04

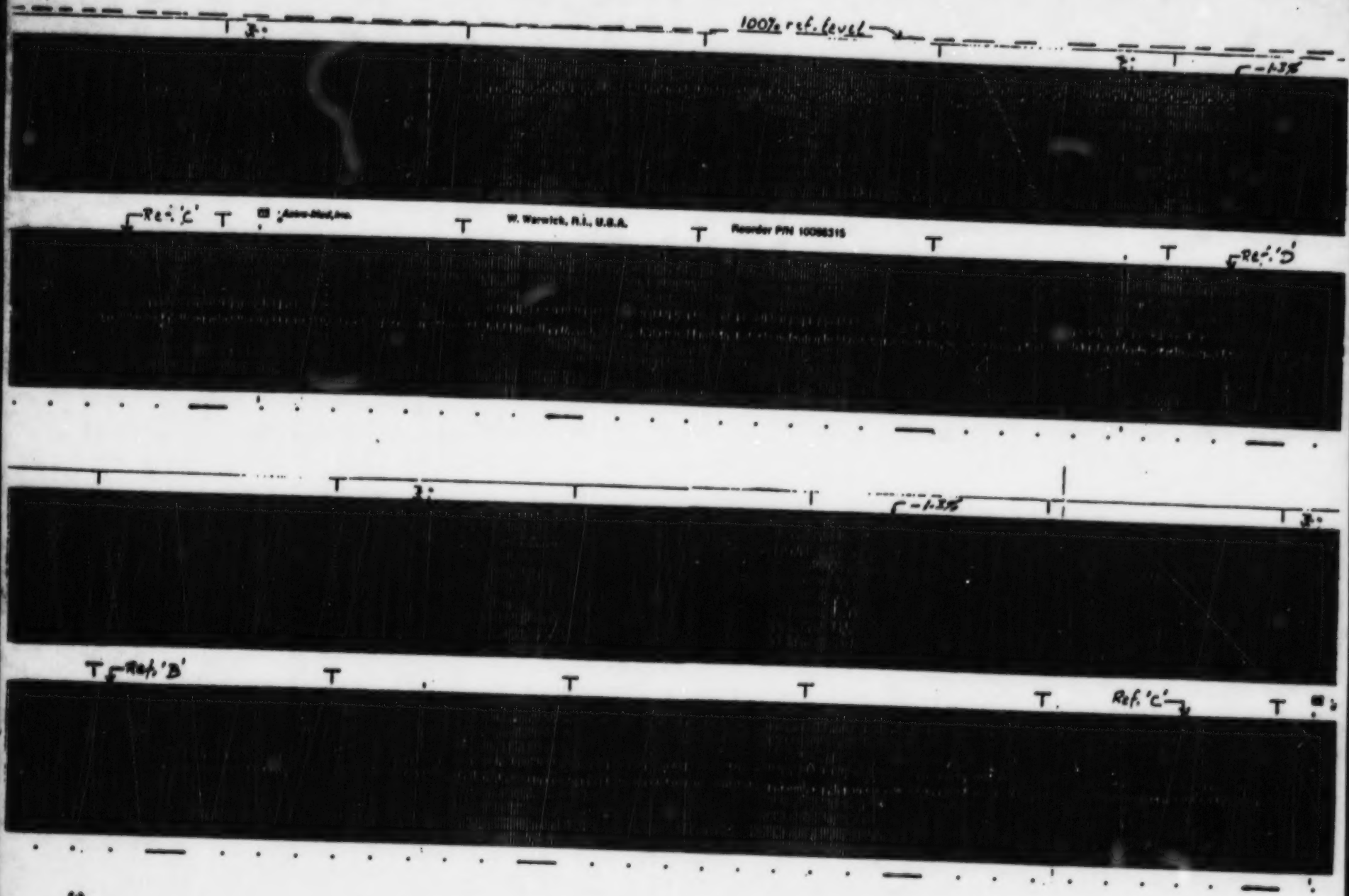

Fig. 3b (continued) — LMA-250, shop-floor chart of 1989 04 04

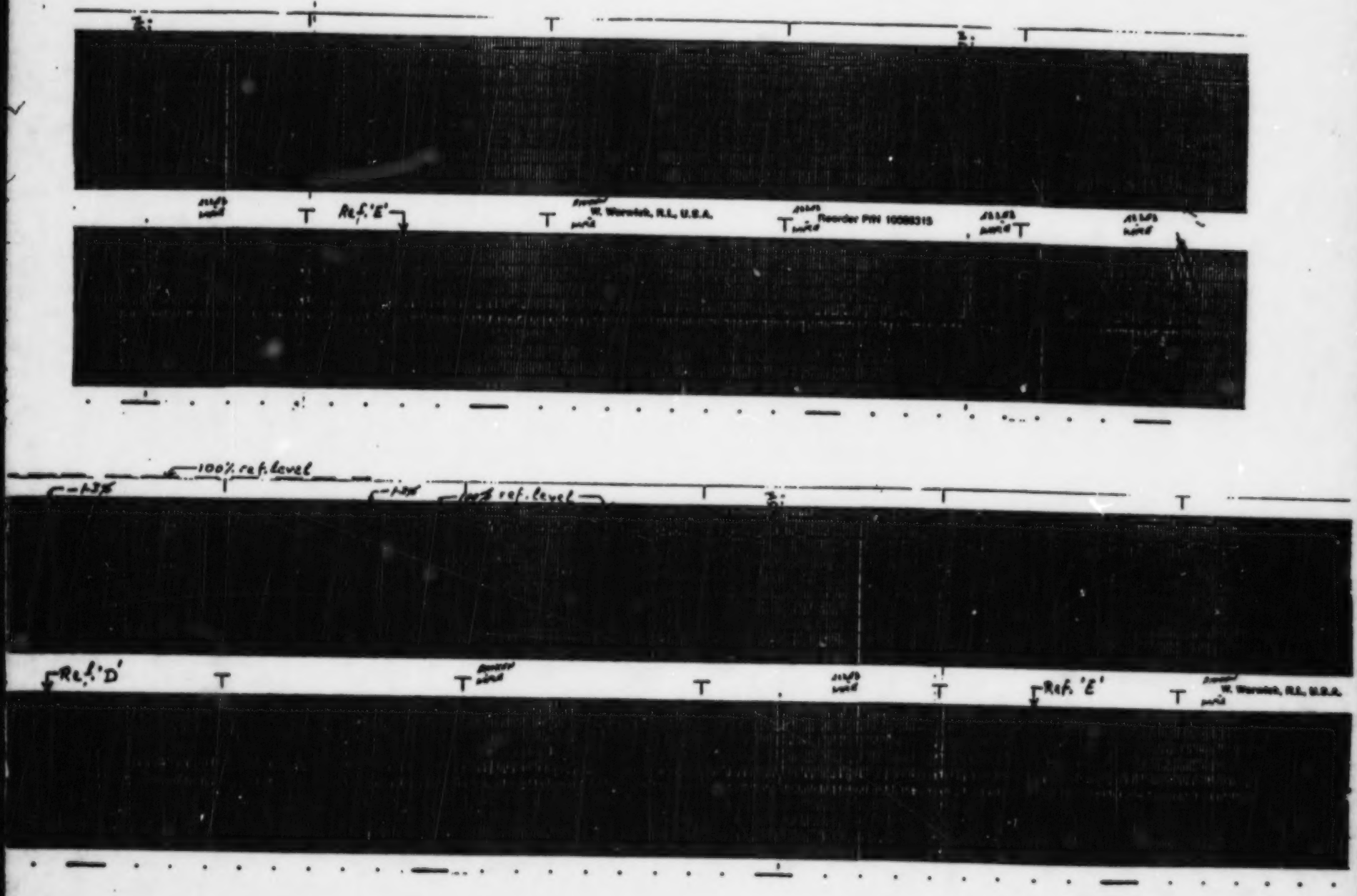

Fig. 3b (continued) — LMA-250, shop-floor chart of 1989 04 04

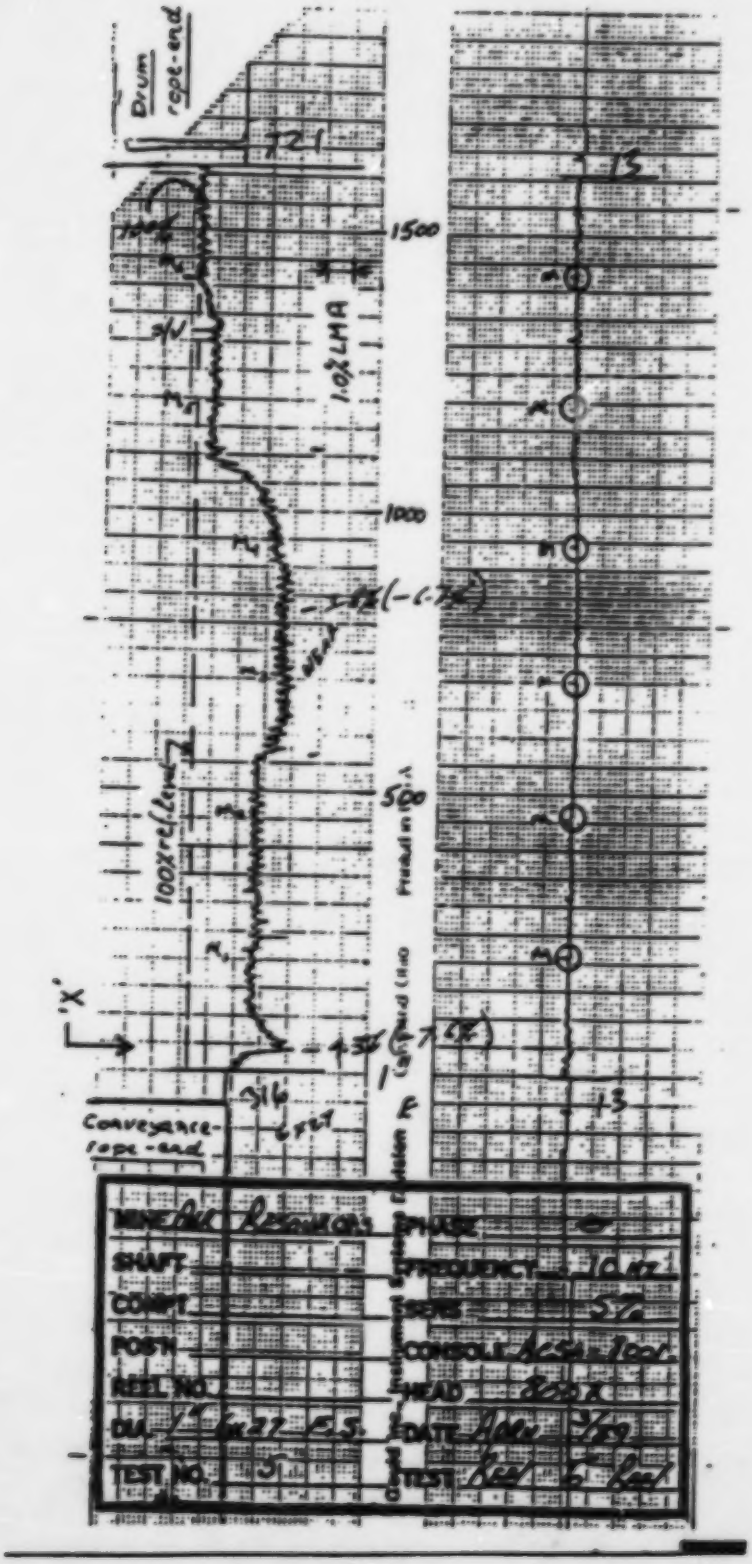

Fig. 4 — Rotesco A.C. shop-floor chart of 1989 04 03

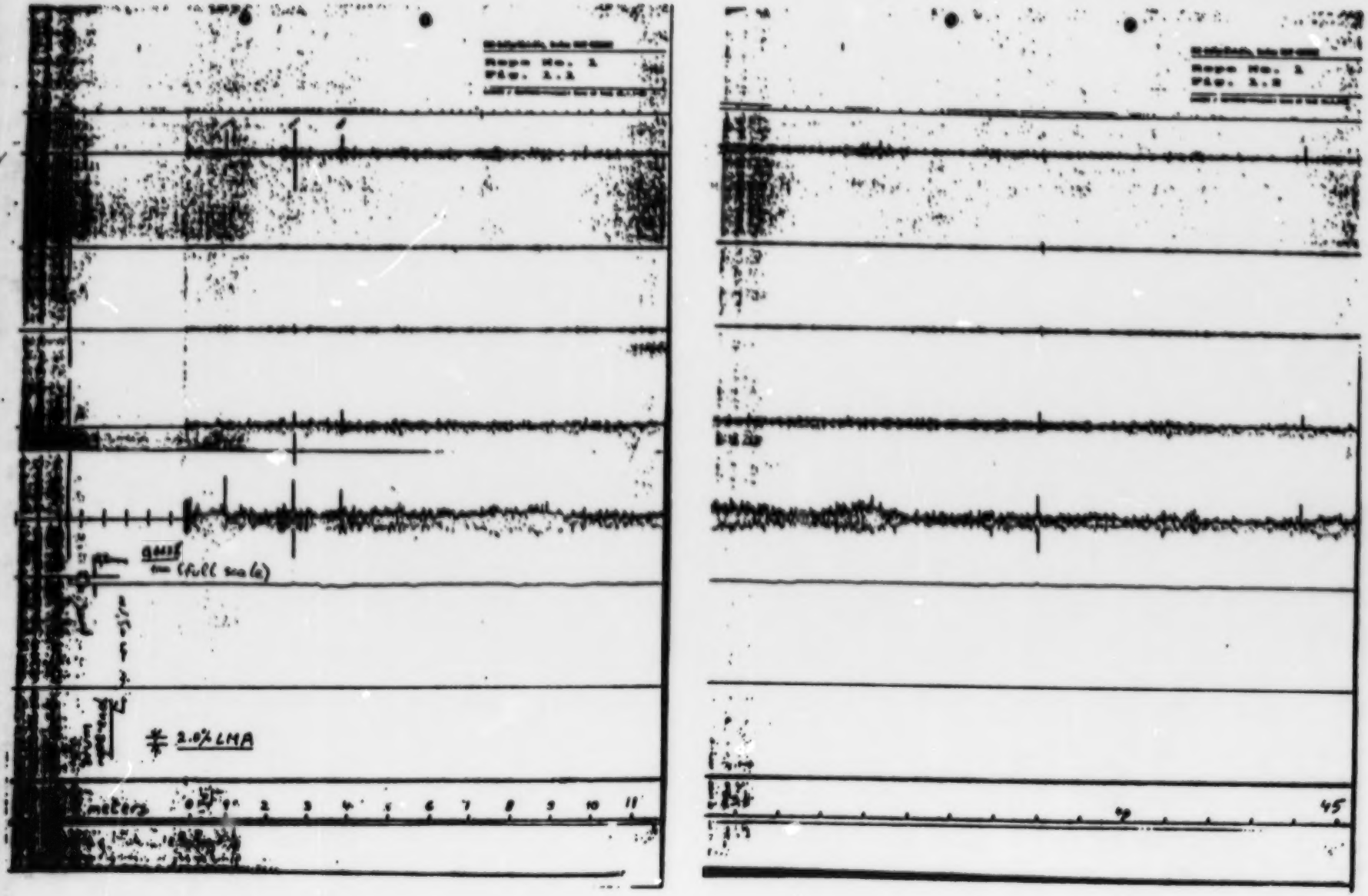

Fig. 5 — WBK, shop-floor chart of 1989 04 10

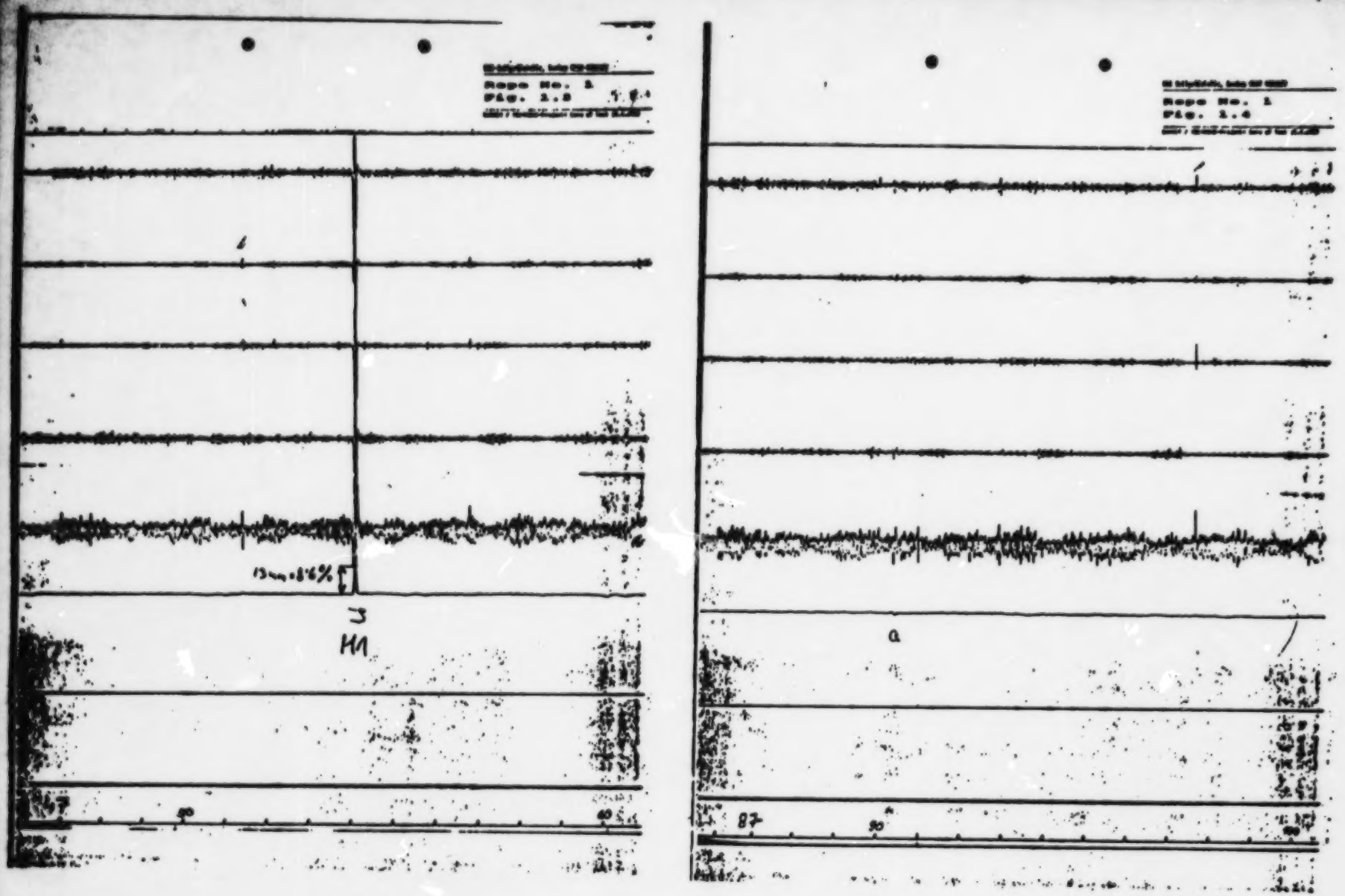

Fig. 5 (continued) — WBK, shop-floor chart of 1989 04 10

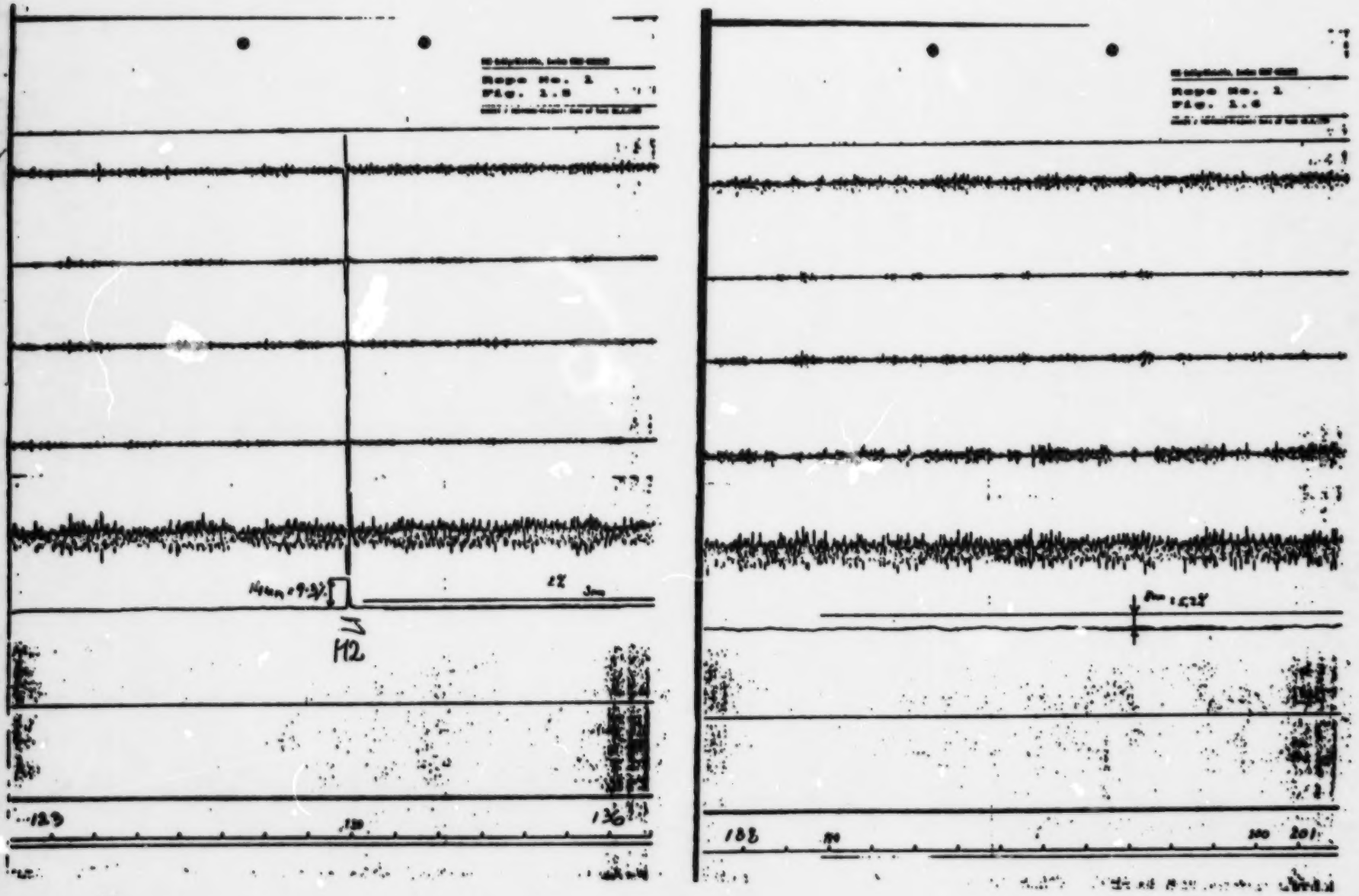

Fig. 5 (continued) — WBK, shop-floor chart of 1989 04 10

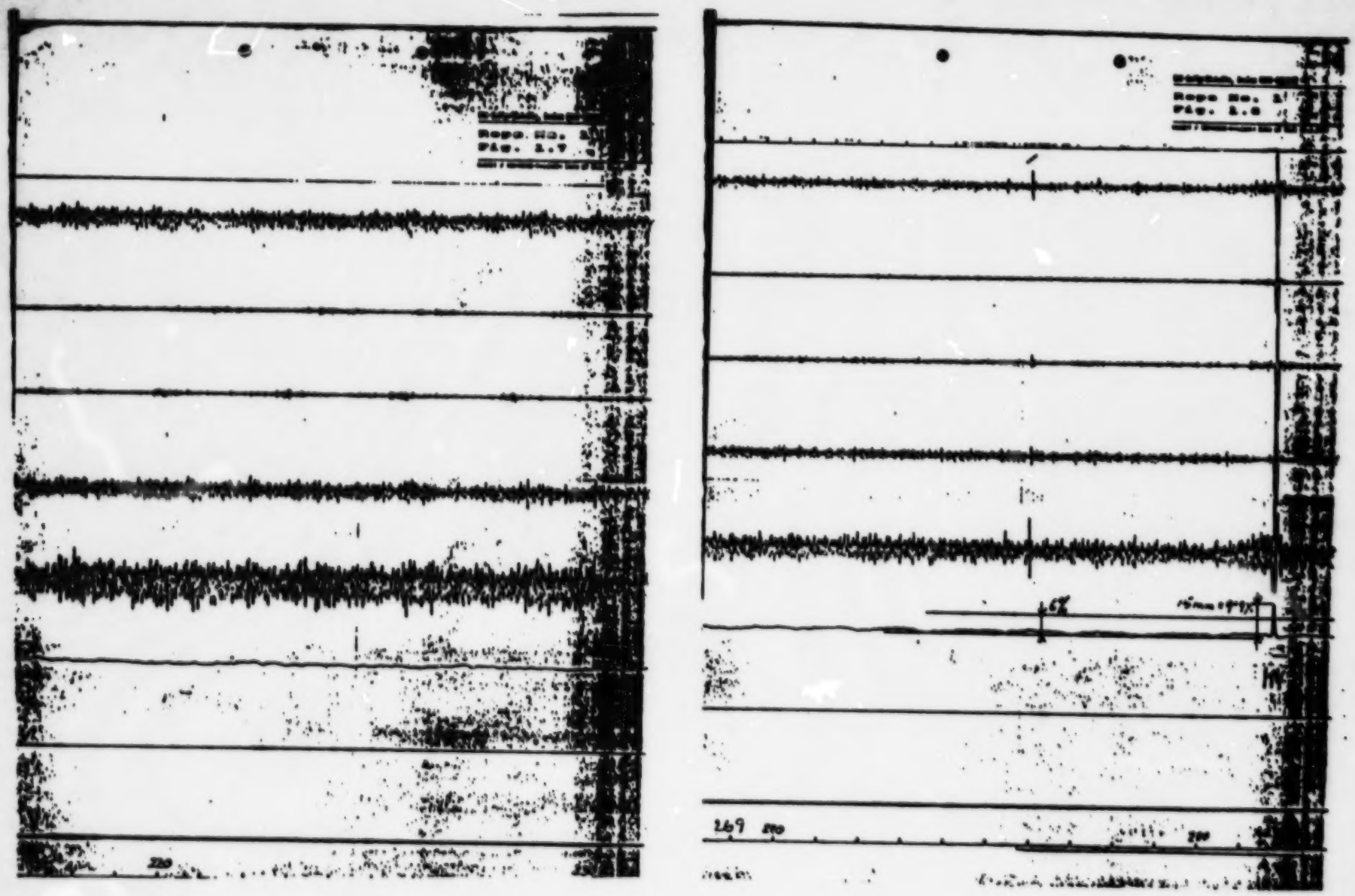

Fig. 5 (continued) — WBK, shop-floor chart of 1989 04 10

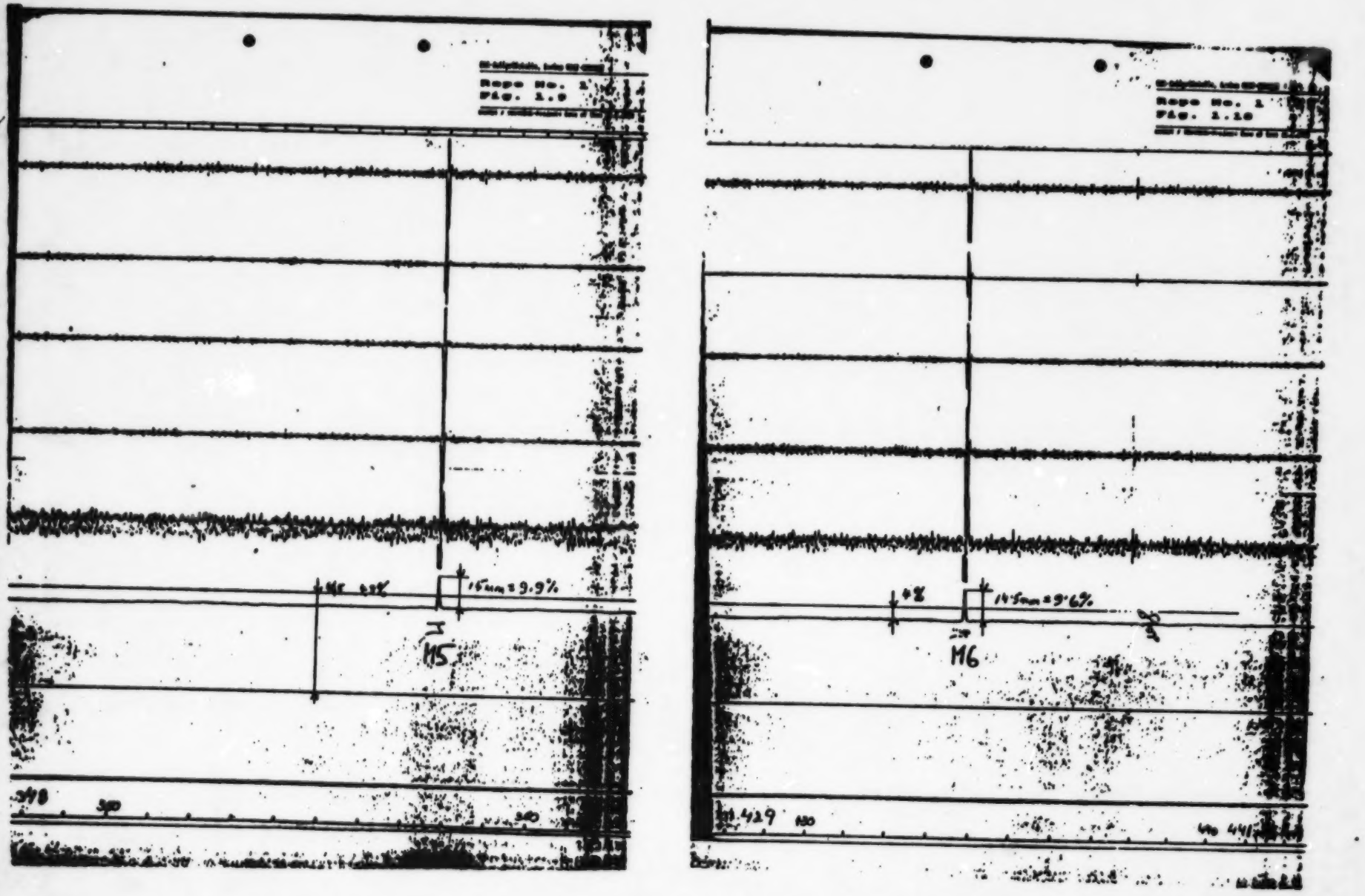

Fig. 5 (continued) — WBK, shop-floor chart of 1989 04 10

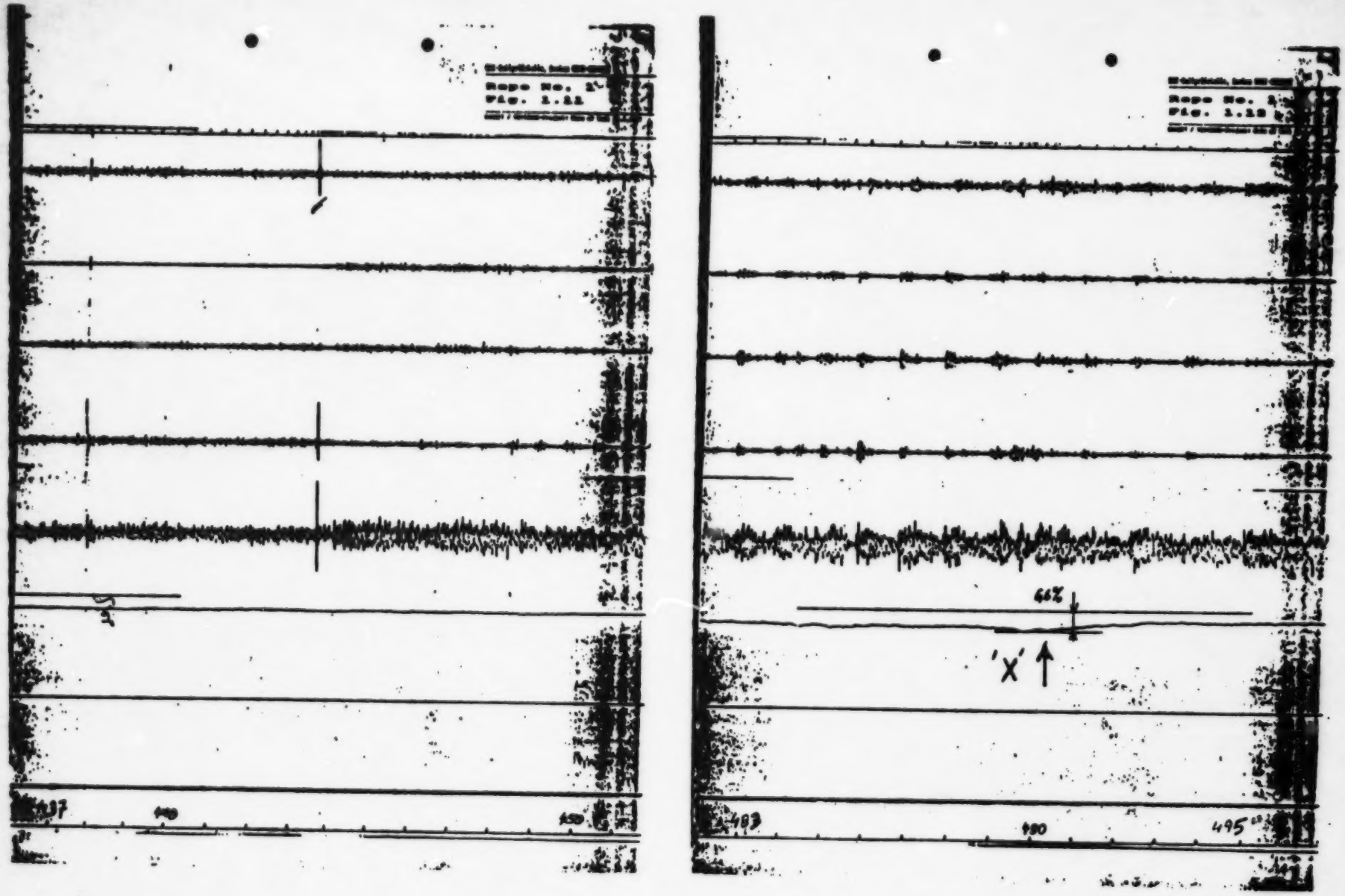

Fig. 5 (continued) — WBK, shop-floor chart of 1989 04 10

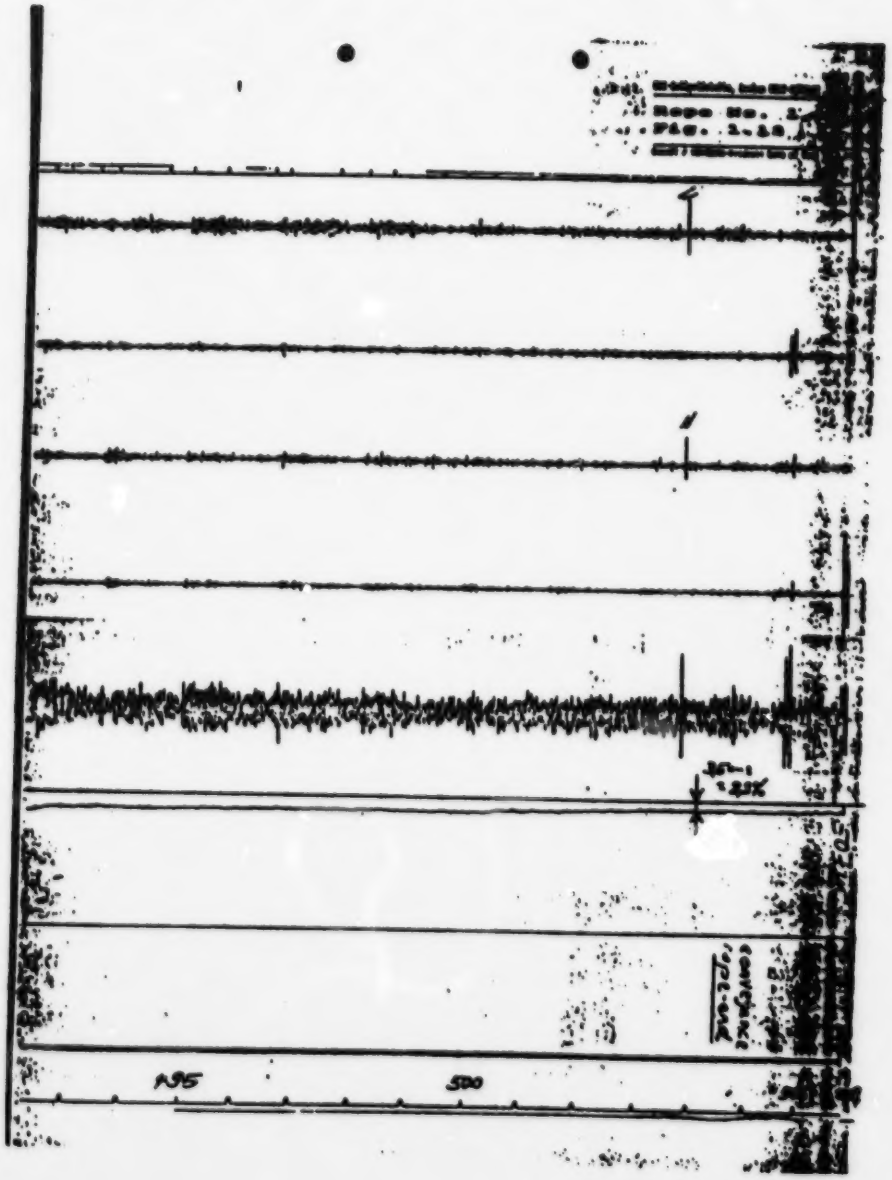

Fig. 5 (continued) — WBK, shop-floor chart of 1989 04 10